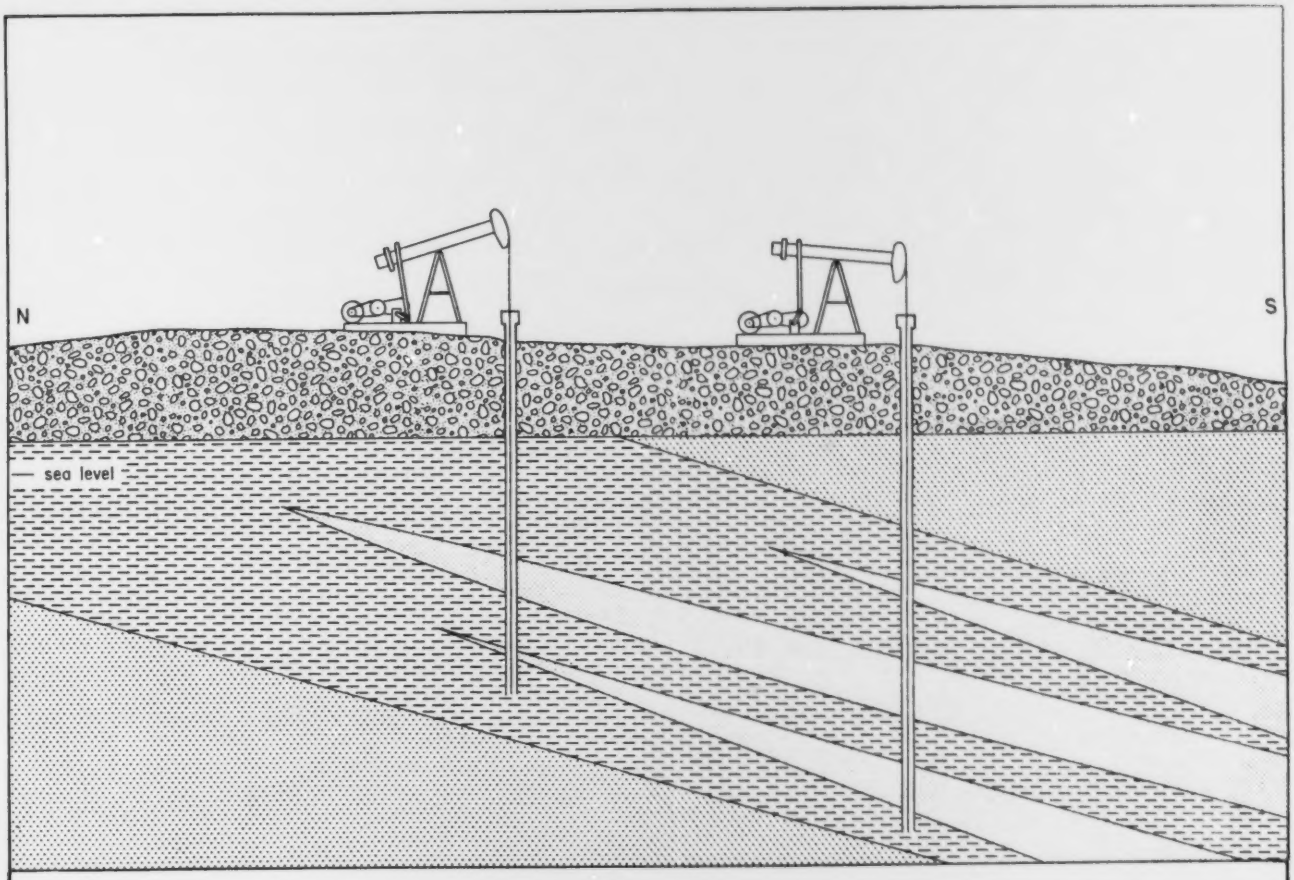
Geoscience Report 89-1

ISSN 0838-2565

GEOLOGY OF THE STONEY CREEK OIL AND GAS FIELD, AND ITS IMPLICATIONS REGARDING THE TECTONIC EVOLUTION OF THE EASTERN MONCTON SUBBASIN, NEW BRUNSWICK



Canada-New Brunswick Mineral Development Agreement

Entente Canada-Nouveau-Brunswick L'Exploitation Minérale

Natural Resources and Energy New Brunswick

Ressources Naturelles et Énergie Nouveau-Brunswick

Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

Price $ 14.00

90-03187/

This report has been prepared for:

Minerals and Energy Division
Department of Natural Resources and Energy
New Brunswick

Hon. Morris Green, Minister

1989

COVER SKETCH:

This is a schematic north-south cross-section of the Stoney Creek Oil and Gas Field showing the south-dipping Albert sandstones pinching out into up-dip shales. The Albert Formation is unconformably overlain by Hopewell Group conglomerates and sandstones.

GEOLOGY OF THE STONEY CREEK OIL AND GAS FIELD, AND ITS IMPLICATIONS REGARDING THE TECTONIC EVOLUTION OF THE EASTERN MONCTON SUBBASIN, NEW BRUNSWICK

This project was funded under the Canada - New Brunswick Mineral Development Agreement, a subsidiary agreement under the Economic and Regional Development Agreement.

Copies available by contacting:

Minerals and Energy Division
Department of Natural Resources and Energy
P.O. Box 6000, Fredericton
New Brunswick E3B 5H1

1989

Report No.: Geoscience Report 89-1

Author: S.L. Foley
University of New Brunswick
Fredericton

Catalogue No.: ISSN 0838-2565

This report should be referenced in the following manner:

FOLEY, S.L. 1989. Geology of the Stoney Creek Oil and Gas Field, and its implications regarding the tectonic evolution of the eastern Moncton Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Geoscience Report 89-1, 77 p.

ABSTRACT

The Stoney Creek Oil and Gas Field is an historic but still-producing field in the Late Paleozoic Moncton Subbasin of New Brunswick. The field is located 16 km south of Moncton. Hydrocarbons are trapped within lacustrine/ marginal lacustrine (shoreface) sands of the Lower Carboniferous Albert Formation. The field lies along the south flank of the Westmorland Uplift, a basement complex around which the eastern part of the Moncton Subbasin is bifurcated.

The lacustrine shales and siltstones of the Albert Formation thicken down-dip towards the south across the Stoney Creek field. Sandstone sequences interbedded with the shales and siltstones also thicken towards the south and presumably into the deeper part of the Moncton Subbasin. The thickening of the Albert Formation away from the Westmorland Uplift indicates that the uplift, which lies directly north of the field, acted as a passive high.

Lower Carboniferous facies distributions, paleocurrent patterns and high-resolution seismic profiles indicate that the major source area for the sediments in the eastern Hillsborough Subbasin (southeastern Moncton Subbasin) was the Westmorland Uplift. Sediments appear to have been shed off the uplift toward the south and west.

The Moncton Fault is a large regional fault which is located north of the Westmorland Uplift along the east-west arm of the Petitcodiac River. This fault had a large north-side-down component of movement. A thick sequence of Lower Mississippian sediments accumulated in the Petitcodiac Subbasin (northeastern Moncton Subbasin) to the north of the Moncton Fault.

A tectonic model for the eastern Moncton Subbasin is advanced based on the interpretation of seismic profiles, known displacements of exposed regional faults and the types and distribution of Upper Devonian and Lower Carboniferous clastic facies. From the evidence, it is believed that the Moncton and Sackville subbasins formed synchronously as en echelon pull-apart basins in response to right-lateral strike-slip tectonics.

Further hydrocarbon exploration in the Moncton Subbasin should concentrate in areas south and east of the Stoney Creek Oil and Gas Field and north of the Westmorland Uplift in the Petitcodiac Subbasin.

ACKNOWLEDGMENTS

I wish to express my gratitude to Dr. J.P.A. Noble, my supervisor, for his support throughout this project.

Special thanks are due to Clint St. Peter for his continued guidance, valued discussions and expertise. He must also be gratefully acknowledged for the contribution of geological data and for the many hours which were required to edit the report and figures.

I wish to thank Ali Chowdhury, for his availing suggestions and discussions on various aspects of the Albert Formation.

Sherri Townsend is gratefully acknowledged for her assistance in the administration of the contract.

I wish to express my appreciation to David Pirie, Ancel Murphy and Scott Sale of the University of New Brunswick, Department of Geology lapidary staff for their skillful thin section work. I would also like to thank Bob McCulloch for his valuable photographic assistance. Susan Dearman, Wayne Egers, Angel Gomez of the UNB Geology Department and the graphics staff of the Department of Natural Resources and Energy are hereby acknowledge for their drafting support.

I would like to express my sincere thanks to my wife Laura who gave her own time to assist me in the field.

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	vi
LIST OF PLATES	x
1 INTRODUCTION	1
1.1 Regional Geology	1
1.2 Physiography	1
2 REGIONAL GEOLOGICAL SETTING	2
2.1 Major Geotectonic Elements	2
2.2 Pre-Carboniferous Basement Complex	2
2.3 Stratigraphy Within The Moncton Subbasin	3
2.3.1 The Memramcook Formation	3
2.3.2 The Albert Formation	3
2.3.3 The Moncton Formation	3
2.3.4 The Windsor Group	5
2.3.5 The Hopewell	5
2.3.6 The Petitcodiac Group	5
3 GEOLOGY OF THE ALBERT FORMATION	7
3.1 Stratigraphic Nomenclature	7
3.1.1 The Dawson Settlement Member	7
3.1.2 The Frederick Brook Member	7
3.1.3 The Hiram Brook Member	7
3.1.4 The Gautreau Member	7
3.1.5 The Round Hill Member	8
3.2 Albert Formation Facies	8
3.3 Paleocurrents in the Eastern Moncton Subbasin	9
3.4 Hydrocarbons of the Albert Formation	9
4 REGIONAL STRUCTURE	10
4.1 Regional Faults Cutting the Carboniferous Rocks of Southern New Brunswick	10
4.1.1 Harvey-Hopewell Fault	10
4.1.2 Belleisle Fault	10
4.1.3 Kennebecasis Fault	10
4.1.4 Clover Hill Fault	11
4.1.5 Dorchester Fault	11
4.1.6 Port Elgin Fault	11
4.1.7 Memramcook River Fault	11
4.1.8 Memramcook East Fault	12
4.1.9 Moncton Fault	12
4.2 Regional Carboniferous Folds Within The Moncton Subbasin	12

Page

5 HISTORY OF HYDROCARBON EXPLORATION IN THE MONCTON SUBBASIN 13

6 THE STONEY CREEK OIL AND GAS FIELD 15
6.1 Data Acquisition, Manipulation and Presentation 15
6.2 Cross-Section Interpretation 16
6.3 Structural Contour and Isopach Map Interpretation 17
6.4 Three-Dimensional Computer Model Interpretation 18
6.5 Hydrocarbon Trapping Mechanisms 18
6.6 Provenance of the Stoney Creek Sands 18

7 REGIONAL SEDIMENTOLOGICAL AND TECTONIC IMPLICATIONS 20
7.1 Implications with Respect to Regional Facies 22
7.2 Reevaluation of the Hydrocarbon Potential in Southeastern New Brunswick 24

8 CONCLUSIONS 28

9 RECOMMENDATIONS FOR FURTHER WORK 29

REFERENCES 30

APPENDIX A - List of symbols, abbreviations and procedures for the New Brunswick standard lithologic well log 36

APPENDIX B - Three-dimensional computer models 61

LIST OF FIGURES

Page

Figure 1: Regional geology and tectonic elements of southeastern New Brunswick . . . . . Plate 88-219 in pocket

Figure 2: Table of formations, Moncton Subbasin, New Brunswick; after Wright (1922), Greiner (1962), Carter and Pickerill (1985b). 4

Figure 3: Simplified geology of the eastern part of the Moncton Subbasin . . . . . Plate 88-220 in pocket

Figure 4: Cross-section location map, Stoney Creek Oil and Gas Field . . . . . Plate 88-221 in pocket

Figure 5: Cross-section AA', Stoney Creek Oil and Gas Field. . . . . Plate 88-222 in pocket

Figure 6: Cross-section BB', Stoney Creek Oil and Gas Field. . . . . Plate 88-123 in pocket

Figure 7: Cross-section CC', Stoney Creek Oil and Gas Field. . . . . Plate 88-224 in pocket

Figure 8: Cross-section DD', Stoney Creek Oil and Gas Field. . . . . Plate 88-225 in pocket

Figure 9: Cross-section EE', Stoney Creek Oil and Gas Field. . . . . Plate 88-226 in pocket

Figure 10: Cross-section FF', Stoney Creek Oil and Gas Field. .. . . . . Plate 88-227 in pocket

Figure 11: Cross-section GG', Stoney Creek Oil and Gas Field. .. . . . . Plate 88-228 in pocket

Figure 12: Cross-section HH', Stoney Creek Oil and Gas Field. .. . . . . Plate 88-229 in pocket

Figure 13: Cross-section II', Stoney Creek Oil and Gas Field. .. . . . . Plate 88-230 in pocket

Figure 14: Structural contour map of the top of sandstone zone 1, Albert Formation, Stoney Creek Oil and Gas Field. Contours in metres below mean sea level. . . . . Plate 88-231 in pocket

Page

Figure 15: Structural contour map of the top of sandstone zone 2, Albert Formation at Stoney Creek Oil and Gas Field. Contours in metres below mean sea level. . . . . Plate 88-232 in pocket

Figure 16: Structural contour map of the top of the Frederick Brook Member, Albert Formation, Stoney Creek Oil and Gas Field. Contours in metres below mean sea level.. . . . . Plate 88-233 in pocket

Figure 17: Structural contour map of the top of sandstone zone 3, Albert Formation, Stoney Creek Oil and Gas Field. Contours in metres below mean sea level. . . . . Plate 88-234 in pocket

Figure 18: Isopach map of sandstone zone 2, Albert Formation, Stoney Creek Oil and Gas Field. Isopachs in metres.. . . . . Plate 88-235 in pocket

Figure 19: Isopach map of the Frederick Brook Member, Albert Formation, Stoney Creek Oil and Gas Field. Isopachs in metres. . . . . Plate 88-236 in pocket

Figure 20: Location of wells at Stoney Creek Oil and Gas Field used to generate the three-dimensional models (see Figures 21-35). A solid circle indicates a presently producing oil well; an open circle surrounded by eight radiating ticks, a presently producing gas well; and an open circle surrounded by four radiating ticks, a nonproducing well. The coordinate axes are in metres. 62

Figure 21: A computer-generated structural contour map of the Enragé Unconformity. Contours represent the depth in metres relative to mean sea level. Coordinate axes are in metres. 63

Figure 22: A computer-generated stacked contour surface of the Enragé Unconformity (orthographic projection, tilt angle of 20 degrees). Vertical scale is in metres relative to sea level. See figure 21 for contour values. 64

Figure 23: A computer-generated transect surface of the Enragé Unconformity (orthographic projection, tilt angle of 20 degrees). Vertical scale is in metres relative to sea level. 65

Page

Figure 24: A computer-generated structural contour map of the upper surface of sandstone zone 1. Contours record the depth in metres below mean sea level. Coordinate axes are in metres. Unbroken "straight" lines are faults. 66

Figure 25: A computer-generated stacked contour surface of the upper surface of sandstone zone 1 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. See Figure 24 for contour values. 67

Figure 26: A computer-generated transect surface of the upper surface of sandstone zone 1 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. 68

Figure 27: A computer-generated structural contour map of the upper surface of sandstone zone 2. Contours record the depth in metres below mean sea level. Coordinate axes are in metres. Unbroken "straight" lines are faults. 69

Figure 28: A computer-generated stacked contour surface of the upper surface of sandstone zone 2 (orthographic projection, tilt angle of 20 degrees). Vertical scalein metres below mean sea level. See Figure 27 for contour values. The wells are gas producers from zone 2. 70

Figure 29: A computer-generated transect surface of the upper surface of sandstone zone 2 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. 71

Figure 30: A computer-generated structural contour map of the upper surface of the Frederick Brook Member. Contours record the depth in metres below mean sea level. Coordinate axes are in metres. Unbroken "straight" lines are faults. 72

Figure 31: A computer-generated stacked contour surface of the upper surface of the Frederick Brook Member (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. See Figure 30 for contour values. 73

Figure 32: A computer-generated transect surface of the upper surface of the Frederick Brook Member (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. 74

Page

Figure 33: A computer-generated structural contour map of the upper surface of sandstone zone 3. Contours record the depth in metres below mean sea level. Coordinate axes are in metres. Unbroken "straight" lines are faults. 75

Figure 34: A computer-generated stacked contour surface of the upper surface of sandstone zone 3 (orthographic proection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. See Figure 33 for contour values. The wells are oil producers from zone 3. 76

Figure 35: A computer-generated transect surface of the upper surface of sandstone zone 3 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. 77

Figure 36: Regional tectonic model illustrating the distribution of basement faults which controlled the geometry of the eastern Moncton Subbasin and Sackville Subbasin. 21

Figure 37. a: Deformation style predicted by distributed-shear high drag concepts of wrench tectonics. Angle (θ) between the principle stress direction (σ_1) and the normal to the fault is 30-45 degrees. b: Deformation style predicted for decoupled transcurrent and thrust deformation along a low drag wrench fault having little distributed shear. Angle (θ) between the principle stress direction (σ_1) and the normal to the fault is small (modified after Mount and Suppe, 1987). 23

Figure 38: Regional facies distributions within the eastern Moncton Subbasin and Sackville Subbasin (refer to Figure 36 for fault geometry). 26

Figure 39: Geological correlation diagram for Irving/Chevron Stoney Creek No. 1 well and Irving/Chevron Hillsborough No. 1 well (for the classification of zones refer to Figures 5-13). 27

LIST OF PLATES

Plates 88-158A(R) and 88-158B(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 62

Plate 88-159(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 68

Plate 88-160(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 73

Plate 88-161(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 80

Plate 88-162(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 83

Plate 88-163(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 84

Plates 88-164A(R) and 88-164B(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 91

Plate 88-165(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 97

Plate 88-166(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 109

Plate 88-167(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 113

Plate 88-168(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 114

Plate 88-169(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 121

Plates 88-170A(R) and 88-170B(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 126

Plates 88-171A(R) and 88-171B(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 128

Plate 88-172(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 131

Plate 88-173(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 133

Plate 88-174(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 134

Plates 88-175A(R) and 88-175B(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 137

Plates 88-176A(R) and 88-176B(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 138

Plate 88-177(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 140

Plate 88-178(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 144

Plate 88-179(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 145

Plate 88-180(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 147

Plate 88-181(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 148

Plates 88-182A(R) and 88-182B(R) - Lithologic log - New Brunswick Gas and Oilfields Ltd. No. 149

Plate 88-183(R) - Lithologic log - New Brunswick Oilfields Ltd. No. 153

Plate 88-184(R) - Lithologic log - New Brunswick Oilfields Ltd. No. 156

Plate 88-185(R) - Lithologic log - New Brunswick Oilfields Ltd. No. 157

Plate 88-186(R) - Lithologic log - New Brunswick Oilfields Ltd. No. 158

Plate 88-187(R) - Lithologic log - New Brunswick Oilfields Ltd. No. 161

Plate 88-188(R) - Lithologic log - New Brunswick Oilfields Ltd. No. 163

1 INTRODUCTION

The Stoney Creek Oil and Gas Field is situated 16 km south of Moncton, New Brunswick, on the west side of the Petitcodiac River (Figure 1). The oil and gas field is held under Lease 74-1 which covers an area of 2,153.7 ha. The lease is presently controlled by Irving Oil Limited.

This report describes the results of a detailed study of the sedimentology, facies relationships and geological setting of the Albert Formation within the Stoney Creek Oil and Gas Field. The purpose of the study was to establish a better understanding of the geology of the Stoney Creek field and apply this knowledge to guide hydrocarbon exploration in southern New Brunswick. Limited field work was conducted in order to assess the provenance and depositional environments of the Albert Formation sandstones. The well cuttings of 31 stategically located wells were relogged in detail. These data were used in conjuction with existing lithologic well data to establish a computer supported subsurface model for the Stoney Creek Oil and Gas Field.

The geological data gathered from the Stoney Creek study have been utilized to interpret the geotectonic evolution of the eastern part of the Moncton Subbasin and the Sackville Subbasin (Figure 1). The data are summarized in an interpretive model describing the regional controls on the reservoir geology.

1.1 Regional Geology

The Acadian Orogeny was a major Devonian geotectonic event which effected the Appalachians. Following orogenic culmination the Maritimes region underwent a phase of stretching and crustal thinning (Bradley, 1982). Subsidence was rapid and accompanied the development of a system of genetically related basin and range structures.

The Moncton and Sackville subbasins, located in southeastern New Brunswick, were initiated in the Late Devonian as a result of the initial phase of crustal thinning.

The Moncton Subbasin is a 200 km long wedge-shaped structure which opens to the northeast. The basin is bound on the north by the New Brunswick Platform and on the south by the Caledonia Uplift. It is bifurcated in the east by the Westmorland Uplift. The Moncton Subbasin is filled predominatly by Upper Devonian to Upper Carboniferous terrestrial deposits (St. Peter, 1982).

The Sackville Subbasin, lying to the southeast of the Moncton Subbasin, is a 35 km long northeast-trending depocentre. The basin is restricted to the north by the Westmorland Uplift and to the east by the Elgin Block (Figure 1) (Martel, 1987). Seismic evidence suggests that the Sackville Subbasin is occupied by a thick sequence of Upper Devonian to Upper Carboniferous strata much the same as that observed within the Moncton Subbasin.

1.2 Physiography

The area of study is situated in the watershed of the Petitcodiac and Memramcook rivers. The tributaries of the two large rivers have dendritic drainage patterns. The western streams drain toward the east into the Petitcodiac River. Regions east of the Memramcook River are drained towards the west and south into the Cumberland Basin.

The topography closely reflects the underlying bedrock. Pre-Carboniferous resistant basement forms rolling highlands comprising the Caledonia Uplift in the south. Carboniferous coarse clastic basin fill also tends to form steep rounded hills. Low lying swampy topography is generally underlain by fine-grained Carboniferous strata. Land use is also very much effected by underlying bedrock. The fine-grained rocks of the Albert and Weldon formations form arable soils whereas the underlying coarser grained clastic units form less productive lands.

Quaternary deposits consist of glacial tills and tidal mud and silt flats. Tidal deposits are concentrated along the Petitcodiac and Memramcook rivers and their tributaries. Glacial deposits are thin and gravel occurrences are rare.

Natural pollution is a problem in some areas and is a reflection of the underlying bedrock. Groundwater contamination occurs as a result of oil and saline waters originating from the Albert Formation and Windsor Group evaporites.

2 REGIONAL GEOLOGICAL SETTING

2.1 Major Geotectonic Elements

The major geotectonic elements of southeastern New Brunswick are outlined on Figure 1. The Moncton Subbasin, as previously stated, is bound on the north by the Belleisle Fault. North of the fault the New Brunswick Platform comprises a basement complex overlain by subhorizontally disposed Upper Carboniferous strata. Within the Moncton Subbasin there are slices of basement which have been brought to the surface within the Indian Mountain Uplift. The Caledonia Uplift restricts the Moncton Subbasin to the south and provided a continuous source of detritus throughout the Upper Devonian and Carboniferous. The Westmorland Uplift which bifurcates the Moncton Subbasin in the east was positive during much of the Carboniferous and acted as an active clastic barrier (Gussow, 1953). The eastern Moncton Subbasin has been subdivided by Worth (1977) into two smaller basins isolated by intervening highlands. These are illustrated in Figure 1 and include the Hillsborough Subbasin south of the Westmorland Uplift and the Petitcodiac Subbasin north of the Westmorland Uplift.

The fault-bounded Sackville Subbasin described by Martel (1987) is controlled by many of the same tectonic elements which control the Moncton Subbasin. The Westmorland Uplift restricts the Sackville Subbasin to the north, and the Port Elgin Block restricts it to the east (Figure 1). The western margin of the Sackville Subbasin is probably controlled at depth by the basement complex of the Caledonia Uplift.

2.2 Pre-Carboniferous Basement Complex

Pre-Carboniferous rocks of southern New Brunswick range in age from Precambrian to Devonian. The rocks have undergone a complex history of deformation and metamorphism (Ruitenberg, et al., 1979; Ruitenberg and McCutcheon, 1982). Continental collision in the Early to Middle Devonian culminated in the Acadian Orogeny. Following the Acadian collision and before continental breakup in the Triassic the northern Appalachian region underwent a period of strike-slip deformation (Webb, 1963). Continental basins were developed in response to this strike-slip regime. The Moncton and Sackville subbasins of southern New Brunswick appear to have developed as an en echelon pair during the late Devonian and Early Carboniferous. Sediment supplied to those subbasins was derived from local highlands. Three possible highland sources for clastic detritus have been postulated for the eastern part of the Moncton Subbasin. The highland areas include the Caledonia Uplift, the Westmorland Uplift and the basement complex underlying the New Brunswick Platform (Figure 1).

The Caledonia Uplift bounds the Moncton Subbasin in the south. The oldest rocks within the Caledonia Uplift are highly metamorphosed carbonate and clastic sedimentary rocks, gneiss and schists of the Green Head Group (Ruitenberg et al., 1973; Ruitenberg and McCutcheon, 1982). These rocks are in fault contact with the late Precambrian Coldbrook Group (Giles and Ruitenberg, 1976). The rocks of the Coldbrook Group are dominantly felsic and mafic volcanics with lesser sedimentary units which have been deformed and metamorphosed in the Fundy Cataclastic Zone (Ruitenberg et al., 1973). The Coldbrook Group has been subdivided into three major volcanic belts (Ruitenberg, et al., 1979). The volcanic belts are separated and intruded by two northeast-trending belts of Precambrian and Paleozoic granitoid rocks.

The Moncton Subbasin in the east is bifurcated by a basement complex, the Westmorland Uplift (Figure 1). An inlier of the Westmorland Uplift is exposed in a large quarry at Calhoun, 19 km southeast of Moncton. Here the basement is diorite which McLeod and Ruitenberg (1978) have speculated intruded the Upper Precambrian rocks of the Coldbrook Group. No direct evidence for this relationship has been presented. A second small basement inlier of sheared granite is exposed 3.5 km north of Memramcook East (Carr, 1968) (Figure 1).

The Westmorland Uplift has also been intersected in several drill holes (St. Peter, 1987a). Killarney Gas and Oil Development Company drilled four closely spaced wells 6 km northwest of the Stoney Creek Oil Field (location 6, Figure 1). The four wells all intersected pre-Carboniferous gabbro at a depth of approximately 120 m. New Brunswick Gas and Oilfields well number 92 at Lower Coverdale, about 6 km north of the oil field intersected granite and schist at 108.2 m (location 7, Figure 1). Granite and schist were also intersected in the New Brunswick Gas

and Oilfields well number 52 at Mud Creek, 3 km north of the field (location 8, Figure 1). At Middlesex, 22 km west of the oil field, the Irving/Chevron Middlesex No. 1 well cut limestone and dolomitic limestone basement at a depth of 1272 m (location 9, Figure 1). The limestone has been interpreted as part of the Green Head Group.

Several wells have been drilled into the Westmorland basement north of Sackville (Martel, 1987 and Figure 1). In this area D'Arcy Cape Bald No. 1 intersected pre-Carboniferous granite basement at 295 m (location 10, Figure 1). D'Arcy Cape Bald No. 2 intersected pre-Carboniferous basement at 392 m (location 11, Figure 1). Shell Westmorland No. 1 intersected massive to schistose granite basement at 149.4 m (location 12, Figure 1). One well was drilled on the Port Elgin Block at the town of Port Elgin by Imperial Oil Limited (Martel, 1987). This well, Port Elgin No. 1, intersected pre-Carboniferous granite at 920.7 m (location 13, Figure 1).

On the Indian Mountain Uplift to the north of Moncton, in the Indian Mountain region, pre-Carboniferous metamorphic greenstone, granite porphyry, syenite, and granite occur near Stilesville (Carr, 1968).

2.3 Stratigraphy Within The Moncton Subbasin

The Moncton Subbasin has been filled predominantly by Upper Devonian to Upper Carboniferous terrestrial deposits (St. Peter, 1982). The stratigraphic nomenclature of the eastern Moncton Subbasin is summarized in Figure 2.

2.3.1 The Memramcook Formation (Late Devonian, Famennian in age, Hacquebard, 1972) defines the base of the sequence and rests with angular discordance on the basement complex. The Memramcook Formation in the type area along Stoney Creek south of Cahoun (Figure 1) is characteristically red in colour and comprises primarily piedmont alluvial-fan deposits (Greiner, 1962) and associated braided fluvial deposits (Carter and Pickerill, 1985b). The formation consists of a lower conglomeratic unit and an upper red shale and sandstone unit (Norman, 1941b). In the type section along Stony Creek (a tributary of the upper Memramcook River, Figure 1) the Memramcook Formation consists of interbedded arkose with pebble conglomerate bands and red shale. Clast compositions are dominated by granite and rhyolite with lesser amounts of mafic volcanics and red sandstones (McLeod and Ruitenberg, 1978). The upper portion of the formation is exposed south of Memramcook West (Figure 1) and consists of red shale containing local interbeds of red sandstone and grey shale (Norman, 1941b).

The Memramcook Formation exposed along the Caledonia Uplift south of Sussex (Figure 1) consists of brownish red fanglomerates and conglomeratic sandstones which grade up into brownish red sandstones and mudstones (McCutcheon, 1978). Clast size decreases off the Caledonia Uplift. The clasts are composed of felsic and mafic volcanic, sedimentary and granitoid rocks which strongly suggest a Coldbrook Group provenance and thus a northward transport direction (McCutcheon, 1978).

2.3.2 The Albert Formation conformably overlies the Memramcook Formation (Gussow, 1953). The Albert strata represent a wide range of continental depositional environments including: alluvial fan, fluvial, deltaic, playa lake, evaporite and carbonate mud flats, and perennial lacustrine (Carter and Pickerill, 1985a). The Albert Formation is differentiated from the underlying Memramcook Formation on the basis of a colour change from red to grey (Gussow, 1953). Palynomorphs and fish fauna collected within the Albert Formation give an age range of Late Devonian to Early Carboniferous (Tournaisian) (Greiner, 1977; Varma, 1969; McLeod, 1980; Utting, 1987). In the Hillsborough area 1363 m of Albert Formation has been intersected in the Irving/Chevron Hillsborough No. 1 well (location 3, Figure 1). The well bottoms within the Albert Formation and therefore represents an incomplete section. St. Peter (1982) estimates the Albert sequence to be greater than 1500 m thick in the southern axial part of the Moncton Subbasin. A more complete description and interpretation of the Albert facies are given below under Geology of the Albert Formation.

2.3.3 The Moncton Formation originally defined as the Moncton Group by Norman (1941a, 1941b) was reduced to formation status by Carter and Pickerill (1985b). An early Carboniferous (Visean) age has been assigned to the group by Hacquebard (1972). The Weldon and Hillsborough formations of the Moncton Group as defined by Norman have been reduced

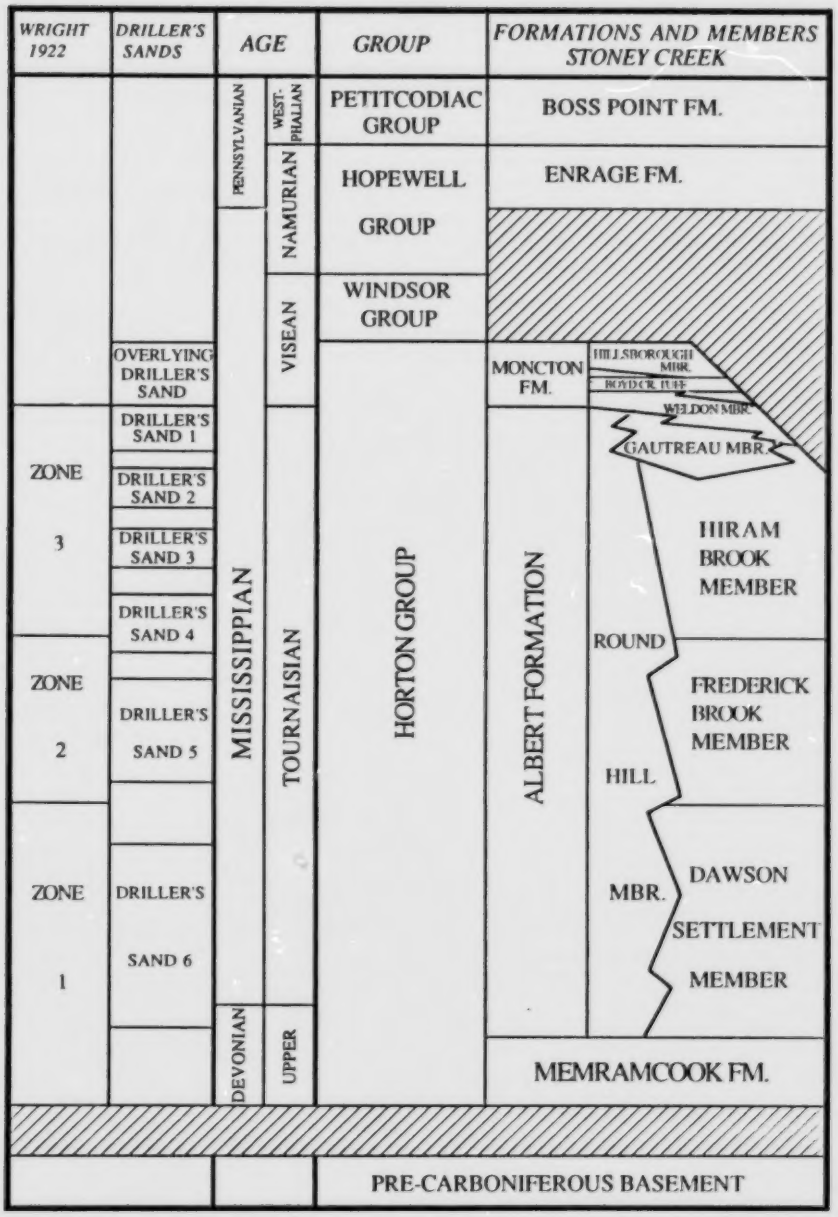


Figure 2: Table of formations, Moncton Subbasin, New Brunswick; after Wright (1922), Greiner (1962), Carter and Pickerill 1985b).

to members status by Carter and Pickerill (1985b). Comprehensive descriptions have been given by Gussow (1953), McCutcheon (1978) and McLeod (1980).

The lower Weldon Member conformably overlies the Albert Formation. The contact is defined by a colour change from grey to red (Gussow, 1953). The type section of the Weldon Member is exposed along Weldon Creek which crosses the southern margin of the Stoney Creek Oil and Gas field (Figure 1). In the type section it is composed of red mudstone and siltstone interbedded with minor green shale. The mudstone and siltstone are thin bedded, calcareous and in places contain limestone nodules. Ripple cross-lamination and mud cracks are commonly observed (Gussow, 1953).

The Hillsborough Member overlies the Weldon Member. The contact is generally conformable but locally an angular unconformity exists (Pickerill et al., 1985). The Hillsborough Member is dominated by a coarse-grained fanglomerate facies. Clast compositions suggest derivation from the Coldbrook Group to the south. A fine-grained distal facies has been recognized in drill holes. A gradational change from sandstones to mudstones to algal laminated limestone of the Windsor Group is apparent in the distal facies (McCutcheon, 1978). Within the eastern Moncton Subbasin the Weldon and Hillsborough members are locally separated by an intervening felsic crystal lithic tuff unit, the Boyd Creek Tuff (Figure 3). The tuff crosses the Weldon/Hillsborough boundary as a time line and provides reliable evidence of a lateral facies change between the Weldon and Hillsborough members (McLeod, 1980).

2.3.4 The Windsor Group was first recognized in southern New Brunswick by Dawson (1873). The Lower Viséan Windsor Group represents the only marine incursion into the Moncton Subbasin (McCutcheon, 1981). A comprehensive description and environmental interpretation of the group has been given by McCutcheon (1981). Other descriptions have been provided by Gussow (1953), McCutcheon (1978), McLeod and Ruitenberg (1978) and McLeod (1980).

In the axial part of the Moncton Subbasin where the Windsor Group is thickest, the lower contact with the Hillsborough Member is conformable. Along the margins of the basin where the group is much thinner the contact becomes unconformable (McCutcheon, 1981).

The Windsor Group within the Moncton Subbasin has been subdivided into six formations and one informal unit which include: Gays River, Macumber, Parleeville, Upperton, Cassidy Lake and Clover Hill formations and the Samp Hill beds (an informal unit). Lithotypes include algal limestone, siliciclastic arenaceous and rudaceous limestone, gypsum, anhydrite, halite and minor packstone, wackestone, shale and potassium chlorides (McCutcheon, ibid.).

McCutcheon (1981) believes that the present day distribution and basin morphology of the Windsor Group is a good approximation of the paleogeography of the Windsor sea and that the paleobasin opened to the northeast.

2.3.5 The Hopewell Group overlies the Windsor and Horton group rocks and is more regionally extensive than the latter two groups. The late Viséan to late Namurian or early Westphalian Hopewell Group as revised by Norman (1941a) is characterized by red conglomerates, quartz-feldspathic sandstones and mudstone (Williams et al., 1985). The Hopewell Group is divided into three formations in the eastern Moncton Subbasin. These include, in ascending order, the Maringouin, Shepody and Enragé formations. The Maningouin Formation of the Hopewell Group conformably overlies the Windsor Group. Along the margins of the Moncton Subbasin where the Windsor Group is absent the Hopewell Group unconformably overlies Lower Mississippian Horton Group rocks or pre-Carboniferous basement.

Within the Stoney Creek Oil and Gas Field the Windsor Group has been eroded and the Moncton Formation is unconformably overlain by the Enragé Formation. In the Stoney Creek area the Enragé is a red, coarse-grained fanglomerate facies (McLeod, 1980). The clasts indicate that the detritus was most likely derived from the Coldbrook Group (McLeod, 1980). The upper contact of the Enragé Formation is considered to be conformable with the overlying Boss Point Formation of the Petitcodiac Group in the eastern part of the Moncton Subbasin (McLeod and Ruitenberg, 1978).

2.3.6 The Petitcodiac Group geology as revised by Norman (1941a) and Carr (1968) is summarized by Williams et al. (1985). The age of the group ranges from Namurian B to

Stephanian (Ball et al., 1981). Three repetitive lithofacies characterize the group. The lower lithofacies is dominated by quartz sandstones and quartz-pebble conglomerates. The middle lithofacies is characterized by medium- to coarse-grained sandstones with abundant plant detritus and minor mudstone. The upper lithofacies is characterized by mudstone, fine-grained sandstone and coal. The Petitcodiac Group has been divided into four formations, in ascending order, the Boss Point, Salisbury, Richibucto, and Tormentine formations. The Petitcodiac Group conformably to disconformably overlies the Hopewell Group.

The Boss Point Formation (Norman, 1941a) is dominated by the lower and middle lithofacies of the Petitcodiac Group. Within the Stoney Creek Oil and Gas Field the Boss Point Formation consists of grey to buff sandstone, pebbly sandstone and quartz-pebble conglomerate.

3 GEOLOGY OF THE ALBERT FORMATION

3.1 Stratigraphic Nomenclature

The Albert Formation is one of the most frequently described and widely recognized unit of rocks in New Brunswick. Its economic potential was realized as early as 1849 with the discovery of the solid bitumen "albertite" at Albert Mines (Pickerill et al., 1985).

The oil drillers at Stoney Creek (Figure 1) were the first to subdivide the Albert Series. They established six workable divisions on the basis of recognizable oil and gas zones and named the zones "driller's sands" 1 through 6 from top to bottom.

Wright (1922) established a simpler division (Figure 2) which could be applied to the Albert Series over an area much broader than the Stoney Creek field. He divided the Albert into three stratigraphic zones with gradational contacts. The top zone, No. 3, consists of interbedded slightly bituminous sandstones and shales. Wright estimated the thickness to be in the order of 1300 m in the Dover area (Figure 3). The middle zone, No. 2, is dominated by high grade oil shale with interbeds of lower grade to barren shale. He estimated the thickness of the zone to be greater than 150 m in the Albert Mines area. The lower zone, No. 1, consists of basal conglomerates grading upward into bituminous sandstones and shales. Wright estimated the thickness of zone No. 1 at Rosevale (Figure 3), to be greater than 150 m.

The Albert Series of Wright (1922) was renamed the Albert Formation and was included as a subdivision of the Horton Series by Norman (1932). Greiner (1962) utilized Wright's (1922) zonal divisions of the Albert Formation and introduced three formal member names (Figure 2): The Dawson Settlement Member of Greiner (1962) is equivalent to driller's sand 6 or zone number 1 of Wright (1922); the Frederick Brook Member is equivalent to driller's sand 5 or zone number 2 of Wright (1922); the Hiram Brook Member is equivalent to driller's sands 1 through 4 or zone number 3 of Wright (1922).

3.1.1 The Dawson Settlement Member is the basal unit of the Albert Formation. A type section was chosen by Greiner (1962) at New Brunswick Gas and Oilfields Limited well No. 166 located near Dawson Settlement (location 14, Figure 1). The member conformably overlies the red beds of the Memramcook Formation and is overlain by a continuous section of kerogenous shales described as the Frederick Brook Member. The Dawson Settlement Member is dominated by coarse- to fine-grained feldspathic sandstones intercalated with pyritic shale. Thickness and lithologic character vary substantially from place to place (Greiner, 1962).

3.1.2 The Frederick Brook Member is the middle member of the Albert Formation. The type section is at Frederick Brook near Albert Mines (Figure 1). The Frederick Brook Member is dominated by kerogenous shale which in many places exhibits a flexible papery morphology. Minor siltstone and sandstone interbeds are present. Palaeoniscid fish skeletons are locally abundant (Greiner, 1962). The member maintains a fairly consistent thickness of approximately 150 m (Greiner, 1962).

3.1.3 The Hiram Brook Member is the uppermost member of the Albert Formation over much of the Moncton Subbasin. A type section was chosen by Greiner (1962) at New Brunswick Gas and Oilfields Limited well No. 104 located on the southern margin of the Stoney Creek Oil and Gas Field (location 15, Figure 1). The Hiram Brook Member comprises an interbedded sequence of kerogenous, calcareous siltstone, shale and sandstone. The Hiram Brook Member grades into the Frederick Brook Member. In the area south and southeast of the Stoney Creek field the Hiram Brook Member grades laterally into the Gautreau Member.

3.1.4 The Gautreau Member was originally defined as the Gautreau Formation by Norman (1932). By Norman's definition it is a lenticular sequence of rock salt which accumulated in a local restricted salt basin in the area between Hillsborough and Stoney Creek (Figure 3). Norman believed that the Gautreau Formation was stratigraphically above the Albert Formation. Greiner (1962) expanded the formation to incorporate certain argillaceous dolomites and anhydritic and gypsiferous beds which were obviously evaporitic in origin. As much as 490 m of rock salt have been intersected in wells drilled near Gautreau Village (Greiner, 1962). Carter and Pickerill (1985b) proposed a stratigraphic revision of the Gautreau Formation by reducing its formational status to a member of the Albert Formation. They believe the Gautreau evaporites developed diachronously and that the member is laterally

equivalent to the upper part of the Hiram Brook Member.

3.1.5 The Round Hill Member was originally defined as the Round Hill Formation by McLeod (1980) and described as a coarse-grained conglomerate unit exposed along the northern margin of the Caledonia Uplift. McLeod (1980) believed the unit warranted formational status based on its mappable continuity and readily defined contacts. The conglomerates were initially interpreted as a coarse clastic facies of the Weldon Formation by Wright (1922) and Norman (1941a). McLeod (1980) recognized that the Round Hill Formation was in part, if not wholly, a facies equivalent of the Albert Formation. As a result of its spacial and temporal relationship, Carter and Pickerill (1985b) relegated the Round Hill Formation to a member of the Albert Formation.

3.2 Albert Formation Facies

The Albert Formation comprises a sequence of continental strata interpreted to have been deposited in alluvial fans, fluvial channels and overbanks, lake deltas, playa lakes and perennial lake environments. Facies evaluations and environmental interpretation have been presented by Greiner 1962, 1974; Pickerill and Carter, 1980; St. Peter, 1982; Carter and Pickerill, 1985a, 1985b; Smith and Gibling, 1987. A fresh-water origin for the Albert Formation has been repeatedly advanced (Henderson, 1940; Greiner, 1962, 1974; King, 1963). Henderson (1940) indicates that fish remains (Palaeoniscus), believed to be of fresh-water origin, have lead some geologists to consider the Albert Formation a fresh-water lacustrine sequence. Greiner (1962) supports this hypothesis with the following evidence: The lack of marine fossils, the abundance of fragile plant material, the presence of palaeoniscus fish skeletons, and the high content of mica and feldspar. Greiner (1962) also demonstrates the remarkable similarity of the Albert Formation with the lacustrine (Eocene) Green River Formation. Greiner (1974) presents further evidence to support a fresh-water origin: The common occurrence of nonglacial varves of laminated carbonate and organic matter in kerogenous shales and the development of symmetrical ripple sets are characteristic of a lacustrine environment. The presence of glauberite within the Gautreau evaporites supports a nonmarine depositional environment and the abundance of kaolinitic clay is also an indication of fresh-water deposition (Greiner, 1974).

Pickerill and Carter (1980) recognized seven subenvironments of deposition within the Albert Formation. These include: alluvial fan; fluvial channel; interchannel/overbank (delta plain); marginal lacustrine (carbonate flat and shoreline); shallow lacustrine (evaporitic and clastic); deep lacustrine; and nearshore bar/beach complex. The summary description given below is taken from Pickerill and Carter (1980) and Worth (1977). The alluvial-fan complex is a coarse conglomeratic facies with associated pebbly sandstones and sandstones. The fluvial-channel sequences are characterized by a basal scour surface overlain by a lag conglomerate and fining- upward sandstone sequences. Intimately associated with the channel sequences are interchannel/overbank deposits which are characterized by a succession of mudstones, siltstones, minor thin sandstones and aphanitic argillaceous dolomites and nodular carbonate (interpreted calcrete) horizons. The marginal lacustrine environment is subdivided into two distinct subenvironments; a marginal carbonate flat and a marginal shoreline. The marginal carbonate flats are distinguished by the abundance of fine-grained dolomitic mudstone which exhibits evidence of emergence as indicated by the occurrence of mudcracks and rain prints. The marginal shoreline facies is characterized by thick sandstones interbedded with mudstone. The sandstones are typically well sorted, horizontal to cross-bedded and contain other sedimentary structures indicative of periodic exposure and reworking by shoreline processes. The shallow lacustrine facies is distinguished from the deeper facies by the indication of periodic subaerial exposure and presence of evaporitic minerals or salt "hoppers" (Greiner, 1962). The deep lacustrine facies is characterized by kerogenous palaeoniscid-bearing varved paper shales. A more exhaustive description of the clastic and carbonate mineralogy and the organic petrography of the lacustrine lithotypes and their environmental interpretation has been given by Smith and Gibling (1987). A nearshore bar/beach environment, characterized by massive carbonate breccias, is locally associated with fluvial-deltaic conglomerates

and shallow lacustrine mudstones and siltstones.

Spatial distribution of the Albert Formation subenvironments and descriptions of the marginal and shallow lacustrine facies have been further refined by Carter and Pickerill (1985a). Evidence from organic petrography and organic carbon analyses, has lead Chowdhury (1988) to suggest a ponded lake model rather than the single lake model purposed by Carter and Pickerill (1985b).

3.3 Paleocurrents in the Eastern Moncton Subbasin

Paleocurrent structures larger then ripple size are scarce within the Albert Formation in the eastern Hillsborough Subbasin. All the measured directions on cross-beds and current ripples within the Albert section around Stoney Creek and east of the Peticodiac River are plotted on Figure 3. Paleocurrents from the Memramcook Formation at the type section south of Calhoun are also plotted on this figure.

The paleocurrent vectors represent an amalgamation of data recorded by both Clint St. Peter and the author. Although the measurements are few they do demonstrate a consistency in orientation. The paleocurrents appear to indicate that the bulk transport of sediment was from the east and northeast.

3.4 Hydrocarbons of the Albert Formation

The close spatial relationship between alluvial fan, fluvial and deltaic sands, and organic-rich lacustrine shales (oil shales) would suggest a high potential for the Albert Formation to produce hydrocarbons. This has been recognized for over a century. Oil seeps and gas springs have been recorded since the eighteen hundreds in the area around Dover, Albert Mines and the Stoney Creek Oil and Gas Field (Figure 1). Gas springs have also been identified in water wells throughout the Moncton Subbasin (Wilson and Ball, 1983). Early hydrocarbon exploration focused on known seepages.

In addition to the presence of conventional hydrocarbons the existence of oil shales within the Albert Formation has stimulated repeated commercial interest. The best known occurrence is located at Albert Mines. Results of Rock-eval pyrolysis and Fischer assays indicate that the high grade Albert Mines oil shale zone yields an average of 93.5 litres of oil per tonne (Macauley and Ball, 1982). Oil yields appear to be controlled by the type and amount of organic material present and the maturation level (Kalkreuth and Macauley, 1984). The Albert Mines deposit holds an estimated reserve of 270,000,000 barrels *in situ* shale oil to a depth of 600 m (Macauley and Ball, 1982; Wilson and Ball, 1983). Shale oil reserves at Albert Mines were calculated for the highest grade bed in the section to a mineable depth of 100 m by St. Peter (1988). He established the average thickness of this bed to be about 19.8 m with an average yield of 94.7 L/t. He estimated the reserves at 5,800,000 barrels, although selective mining of the richer beds above the high grade bed would increase those reserves considerably.

Rock-eval analysis of the oil shales in the south and east of the Hillsborough Subbasin (Chowdhury *et al.*, 1989) demonstrates that the lacustrine sequence there contains high total organic carbon and a high hydrogen index as well as a high Tmax, indicative of Type I organic matter. Petrographic examination of the organics shows a predominance of lamalginite (see also Smith, 1985). Organic geochemistry and organic petrography of laminated shales within the Stoney Creek Oil and Gas Field are very different. Low total organic carbon, low hydrogen index and a predominance of vitrinite, sporinites and fusinites indicate a low hydrocarbon potential for these shales. A comparison of shale oil produced by pyrolysis and the crude oil from the Stoney Creek Oil and Gas Field suggests that the Stoney Creek oil was generated and migrated from the thermally mature oil shales to the south and east of the field and not from the interbedded shales within the reservoir sandstones (Chowdhury *et al.*, 1989).

4 REGIONAL STRUCTURE

4.1 Regional Faults Cutting the Carboniferous Rocks of Southern New Brunswick

4.1.1 Harvey-Hopewell Fault: The Harvey-Hopewell master fault of Gussow (1953) lies parallel to the south margin of the Caledonia Uplift and separates the uplift from the Cumberland Basin to the south (Figure 1). Gussow (1953) interpreted the fault as a northwest-directed thrust overriding the Caledonia Uplift. This interpretation was supported by Ruitenberg and McCutcheon (1982) who observed thrusting along the fault and the superposition of Mississippian rocks onto Pennsylvanian strata. Webb (1963) presented both structural and stratigraphic evidence indicating about 18 km of left-lateral displacement with concurrent folding and thrusting during the Pennsylvanian. Webb's argument was based on the apparent displacement of alluvial fans. Webb (1969) clarified his 1963 conclusion by conceding to a possible right-lateral displacement or thrust movement along the Harvey-Hopewell Fault during post-Windsor time in response to regional stresses. His evidence of right-lateral movement came from regional or paleotectonic considerations rather than field evidence. The Pennsylvanian sinistral displacement may have been a readjustment complicated by salt tectonism.

On the basis of sedimentological and seismic indicators the author believes that substantial strike-slip movement did occur along the Harvey-Hopewell Fault. If the Caledonia terrane moved as a discrete block then a sinistral sense of displacement is implied during the Mississippian.

4.1.2 Belleisle Fault: The Belleisle Fault (Figure 1) has been mapped from the Bay of Fundy in the southwest to Havelock in the northeast, a distance of 150 km (McCutcheon and Robinson, 1987). The Belleisle Fault defines the northern boundary of the Moncton Subbasin (St. Peter, 1982).

Gussow (1953) interpreted the fault as a northwest-dipping thrust, based on the evidence at a location north of Havelock, where pre-Carboniferous volcanics were interpreted to overthrust Moncton "red beds".

Webb (1963, 1969) estimated 64 km of right-lateral offset on the Belleisle Fault. He supported his hypothesis by establishing the relationships between the orientations of fold axes and small faults with respect to the major regional structure. Webb concluded that the major structure developed in response to a regional compression oriented east - west at some time after lower Moncton Formation deposition and prior to deposition of the early Pennsylvanian Hopewell Group. Webb also hypothesized a change in the regional stress orientation during post-Moncton time to a more north-south direction. He believed it was this later stress field which resulted in the formation of open folds with axes parallel to the major fault structures.

Leger (1986) completed a fracture analysis along a western segment of the Belleisle Fault and established a qualitative maximum stress orientated east-west. He indicated that the first stage of brittle deformation during the Late Devonian/Early Carboniferous time was right-lateral and complemented the Acadian ductile movement along the fault as proposed by Leger (1986) and Leger and Williams (1986). A reorientation of the stress field did occur between pre- and post-Carboniferous time as indicated by the presence of low-angle thrusts (Leger, 1986).

McCutcheon and Robinson (1987) indicate that during the Late Devonian to Early Carboniferous the Belleisle Fault and other northeast-trending faults in the Moncton Subbasin experienced dip-slip movement. They believe stratigraphic evidence supports this conclusion although they do concede the possibility of limited right-lateral displacement.

4.1.3 Kennebecasis Fault: The Kennebecasis Fault, originally defined by Gussow (1953) as the Peekaboo-Petitcodiac-Berry Mills master fault, can be traced for 120 km across the northern part of the Moncton Subbasin (Figure 1). Gussow interpreted this fault to be a low angle thrust.

Webb (1969) estimated 37 km of right-lateral displacement along the Kennebecasis Fault. He closely tied the movement with that of the Belleisle Fault and utilized Horton Group isopachs to establish the magnitude of displacement.

A structural study, including fracture analysis, lead Leger (1986) to conclude that the latest brittle stage of deformation along the Kennebecasis Fault was dextral strike-slip.

St. Peter (1987b) presented structural and stratigraphic evidence which questioned Gussow's (1953) thrust model. St. Peter provides evidence from the Indian Mountain area which suggests that the fault moved down on the south side.

4.1.4 Clover Hill Fault: The Clover Hill Fault trends northeastward along the north margin of the Caledonia Uplift from Urney in the west to Pollett River in the east (Figure 1). The Pollett River, Prosser Mountain, Caledonia, Salem and Hillsborough faults (Figures 1 and 3) are believed to be subsidiary features of the Clover Hill Fault system (Gussow, 1953). Gussow interpreted the faults as low-angle thrusts with the north block overriding the south block.

Webb (1969) assigned right-lateral slip of 13 km on the Clover Hill Fault. The magnitude and sense of slip was tenuously based on the displacement of basement/cover contacts. As indicated by St. Peter (pers. com., 1988) the apparent displacement of basement rock may be accounted for by upward movement on the northwest side of the fault making lateral displacement unnecessary. The Clover Hill Fault system was active during the Lower Carboniferous. The resulting escarpment gave rise to Horton Group fanglomerates (Leger, 1986; Pickerill et al., 1985 and St. Peter, pers. com., 1988).

Leger (1986) performed a fracture analysis at several localities along the Caledonia Fault (Figure 1). Leger concluded that the overall nature of the fault movement during the Middle to Late Devonian to Early Carboniferous was difficult to establish but evidence did point to the possibility of right-lateral displacement. The magnitude of such movement was indeterminable. Right-lateral displacement is also indicated by the eastward displacement of fanglomerate deposits on the north side of the Caledonia Fault (St. Peter, pers. com., 1988). A substantial right-lateral component of movement on the Clover Hill Fault system is indicated from the geotectonic model proposed from the present study (discussed later).

4.1.5 Dorchester Fault: The Dorchester Fault (Figure 1) was interpreted by Gussow (1953) to be a low angle, northwest-dipping thrust, and an eastward extension of the Clover Hill Fault system. McLeod (1980) demonstrated that the Dorchester Fault was not a continuation of the Clover Hill Fault and in fact terminated within the Caledonia crystalline basement to the south. McLeod recognized the steep dip and opposing senses of displacement on the splays of the eastern Caledonia Fault system and believed the evidence to be consistent with dip-slip or strike-slip movements rather than thrusting.

The acquisition and interpretation of Chevron Canada Resources Ltd. seismic reflection profiles by Martel (1987), has allowed a more complete understanding of basin tectonics within the eastern Moncton Subbasin and Sackville Subbasin. For example it is seen that the Dorchester Fault defines the boundary between the Sackville and Moncton subbasins. East of the Moncton Subbasin the Dorchester Faults defines the boundary between the Westmorland Uplift and the Sackville Subbasin. The seismic data indicates a very large normal down-to-the-south throw on the Dorchester Fault. Martel believes that the tectonic history of the Sackville Subbasin supports a regional strike-slip model as earlier proposed by Webb (1963, 1969) and Bradley (1982). Martel (1987) interpreted the Dorchester Fault to represent a major syndepositional active strike-slip margin developed in a transtensional regime.

4.1.6 Port Elgin Fault: The west-dipping Port Elgin Fault is illustrated on Figure 1. This fault was identified from seismic profiles by Martel (1987) and defines the east boundary of the Sackville Subbasin. Seismic profiles across the fault reveal a large normal down-to-the-west component of movement.

4.1.7 Memramcook River Fault: The existence of a fault along the Memramcook River was originally proposed by McLeod and Ruitenberg (1978). They postulated limited post-Pennsylvanian right-lateral displacement. The fault was interpreted to extend from the mouth of the Petitcodiac River northward to the headwaters of the Memramcook River.

Martel (1987) placed some constraints on this fault. He used it to define the western boundary of the Sackville Subbasin. He inferred its existence from the fundamental change in seismic signature across the Memramcook River valley. However, seismic

evidence does not support the existence of the Memramcook River Fault on the north side of the Dorchester Fault.

4.1.8 Memramcook East Fault: The Memramcook East Fault, illustrated on Figure 1, is a north-south trending fault which lies immediately north of the village of Memramcook East. The fault was originally shown on Norman's (1941b) Moncton geological map sheet 646A. The existence of this fault has been confirmed by recent mapping (St.Peter, pers. com., 1988). South of the village of Memramcook East the southern extension of the fault is concealed under Pennsylvanian strata. An outcrop of Westmorland crystalline basement rock has been mapped by Norman (1941b) immediately east of the north extension of the fault (Figure 1, 3). It is believed that the Memramcook East Fault defines the eastern limit of the Moncton Subbasin and that it extends south under the Pennsylvanian strata where it terminates against the east-west-striking Dorchester Fault. This is supported by the outcrop of crystalline basement rock immediately to the east of the fault and the change in seismic signature across the zone. Available evidence indicates a normal sense of movement with the eastern Westmorland Uplift occupying the footwall side.

4.1.9 Moncton Fault: The Moncton Fault as herein defined and illustrated on Figure 1, delimits the northern flank of the Westmorland Uplift. The fault coincides with the east-west arm of the Petitcodiac River valley west of Moncton. The Moncton Fault is interpreted from seismic reflection profiles which show that it dips to the north into the Petitcodiac Subbasin and appears to have a large component of down-to-the-north normal displacement. Strike-slip movement on the fault could not be determined from the seismic sections. The basin tectonic model proposed (described later) implies that the Westmorland Uplift moved as a discrete block and if so a component of left-lateral displacement would be expected on the Moncton Fault.

4.2 Regional Carboniferous Folds Within The Moncton Subbasin

Three generations of folding have been recognized within the Moncton Subbasin (McCutcheon, 1978; McLeod and Ruitenberg, 1978; McLeod, 1980). A large F1 synclinal structure plunges gently toward the southwest from the Dorchester-Memramcook area to the Hillsborough area (Figure 3). F1 deformation was restricted to the the Horton Group (McLeod and Ruitenberg, 1978; McLeod, 1980). Northeast-trending upright close to tight folds which plunge gently toward the southwest appear to be related to the F1 phase (McLeod, 1980). These folds occur both at the outcrop and map scale. McLeod and Ruitenberg (1978) recognized a locally developed fracture cleavage which appeared to be related to this deformation event. Webb (1969) believed that the initial phases of deformation during the Lower Carboniferous were related to dextral wrenching in an east-west principle stress field and fold orientations were developed in an en echelon geometry in response to movement on the master faults.

McLeod (1980) observed refolding of F1 by northerly trending open F2 folds which are prevalent near the Caledonia Uplift. McCutcheon (1978) describes a similar fold style south of Sussex and adjacent to the Caledonia Uplift.

Deformed Windsor Group rocks and the presence of an unconformity between the Windsor strata and the overlying Enragé Formation may indicate a third folding event (McLeod and Ruitenberg, 1978). F3 structures have been recognized as northeasterly to easterly trending folds that deform Pennsylvanian and older strata (McLeod and Ruitenberg, 1978; McCutcheon, 1978). There appears to have been a reorientation of the principle stress field from east-west to northwest-southeast. The latter direction is approximately perpendicular to the major fault systems (Webb, 1963, 1969).

5 HISTORY OF HYDROCARBON EXPLORATION IN THE MONCTON SUBBASIN

History of hydrocarbon exploration in the Moncton Subbasin has been summarized previously by Hume, 1932; Henderson, 1940; Gussow, 1953; Howie, 1968; Pickerill et al., 1985; Carroll, 1984; Barnett, Martel and Shaw, 1985.

The discovery of a vein of solid bitumen "albertite" by John Duffy, in 1849 initiated the first commercial interest in hydrocarbons in the Carboniferous of New Brunswick (Pickerill et al., 1985). The first wells which yielded oil and gas were drilled by Dr. H.C. Tweedel, a refiner from Pittsburgh, in 1858. The wells were shallow and located near outcrops of known oil seepage in the Dover-Saint Joseph area between the Petitcodiac and Memramcook Rivers (Figure 1). Small flows of oil and gas were found but exploration was discontinued as a result of a drop in oil prices caused by the discovery of large quantities of oil in Pennsylvania (Hume, 1932).

The merger of two companies, St. Joseph Petroleum Company and Emery Oil Company, in 1876, kindled new hope for hydrocarbon exploration in New Brunswick. Several wells, ranging in depth from 300 to 580 m, were drilled in the Dover - Saint Joseph area. Flooding of wells and a declining oil price lead to the abandonment of the venture which saw only limited success (Howie, 1968).

In 1899 the New Brunswick Petroleum Company was formed from local interest. The company was initially granted a five-year licence to prospect and develop oil and gas over a 46,600 km^2 area of New Brunswick. This licence was later converted into a 99-year lease (lease 115), with a renewal clause for an additional 99 years, which gave the New Brunswick Petroleum Company exclusive oil and gas rights to 25,900 km^2 of land, covering much of the Carboniferous basin (Henderson, 1940, Howie, 1968, Carroll, 1984). Initial interest again centered in the Dover - Saint Joseph area. During the period from 1903 to 1905, 72 shallow wells were completed in that area. Three thousand barrels (bbls) of oil were produced from those wells before abandonment in 1905 (Howie, 1968).

In 1908, Maritimes Oilfields Ltd., a company formed by J.A.L. Henderson, financed by Scottish and English capital, bought the long-term lease held by New Brunswick Petroleum Company (Henderson, 1940). Exploration began in the Stoney Creek area and with the drilling of the third deep well the Stoney Creek Field was discovered in 1909. The discovery well had an initial flow rate of 14,158 m^3 of gas and several bbls of oil per day (Henderson, 1940). With the drilling of subsequent wells within the field large volumes of gas were found and developed for marketing in Moncton and Hillsborough.

A private Scottish company, New Brunswick Gas and Oilfields Ltd., was formed in 1915 and acquired the Maritimes Oilfields exploration lease. By 1940 126 deep wells had been drilled at Stoney Creek, with the deepest being 1372 m. Twenty-seven (27) of the wells were exploratory and 99 were drilled for development and definition of the oil field (Henderson, 1940). All wells were drilled using percussion drilling tools. By 1938 the Stoney Creek field had delivered 5.00×10^8 m^3 (1.75×10^{10} ft^3) of gas and 240,000 bbls of oil (Henderson, 1940).

New Brunswick Gas and Oilfields Ltd. was purchased by New Brunswick Oilfields Ltd. in 1947 who farmed-out part of the holdings to the Shell Oil Company (Howie, 1968). Shell Oil undertook gravity and seismic surveys and a four-well drilling program in the Moncton Subbasin (Gussow, 1953). The Shell exploration program under the guidance of W.C. Gussow (1953) succeeded in publishing the first comprehensive documentation of the geology of the Stoney Creek Field and Moncton Subbasin.

In 1954 New Brunswick Gas and Oilfields Ltd. entered into an agreement with O.H. Parker of Kansas. By the terms of the agreement Parker was to earn an interest if he could achieve a required increase in production on the lease. Eight wells were drilled - labelled P-1 through P-8. Unfortunately the required production increases were not met and the agreement lapsed (Howie, 1968).

A gravity and seismic survey and the drilling of seven additional wells in the Moncton Subbasin were begun in 1957 by Imperial Oil Ltd. under a partnership with Shell and a farm-out agreement with New Brunswick Gas and Oilfields. No discoveries resulted from the Imperial program (Howie, 1968 and Barnett et al., 1985).

In 1958 the 99 year lease agreement

between the Province of New Brunswick and New Brunswick Oilfields Ltd. was revised. The term of the lease was reduced to 21 years and in 1960, 12,149 km^2 of land were reverted to the Crown.

In 1962 Western Decalta Petroleum Ltd. of Calgary, Alberta, purchased New Brunswick Oilfields Ltd. Western Decalta attempted a water flood secondary recovery scheme on the Stoney Creek Field. A lack of understanding of the geology of the field resulted in watering out some of the good producing wells (Barnett et al., 1985) and consequently the project was abandoned.

Western Decalta sold the Stoney Creek Oil and Gas Field to Aldis Petroleum in 1974 who in turn sold it to Eastern Canada Hydrocarbons Ltd. in 1977. Irving Oil Limited purchased the field from Eastern Canada Hydrocarbons; Irving is the present lease holder and operator.

On January 1, 1979 lease 115 was terminated. With the exception of those lands under production, all land was returned to the Crown or converted to licences to search (licence numbers 80-1 to -29). Under new regulations, onshore licenses can be held for eight years whereupon at least 50 percent of the land holdings must be relinquished to the Crown in a closely controlled "checker board' arrangement. Those lands retained by the licencee are converted to oil and natural gas leases with ten-year renewable terms.

A partnership between Chevron Canada Resources Ltd. and Irving Oil Ltd. farmed into Western Decalta's licences to search in the early nineteen eighties. In 1983 Chevron carried out 583 km of reflection seismic and gravity surveys (Carroll, 1984). During 1984 Chevron et al. shot an additional 168.6 km of seismic (Barnett and Martel, 1985) and obtained two additional licences (83-4 and 83-5) located north of Moncton. During 1985 four holes were drilled (Stoney Creek No. 1, East Stoney Creek No. 1, Hillsborough No. 1, and Little River No. 1) (Carroll, 1986). An additional hole was drilled at Lee Brook by Irving/Chevron in 1986. Oil and natural gas licences to search 80-1 through 80-29 (held by Western Decalta, Irving Oil and Chevron Resources) expired in December of 1987. All land was dropped with the exception of three areas: one directly south of the present Stoney Creek Oil and Gas Field and two located between the Petitcodiac and Memramcook rivers. These lands were converted in January, 1988, to leases 80-1, 80-2 and 80-3 which occupy a total area of 11134.8 ha (St.Peter, pers com., 1988).

The Stoney Creek Oil and Gas Field (lease 74-1) is still held by Irving Oil Ltd. The field's current production statistics are as follows: Total oil production as of June 30, 1988 was 802,925 bbls; total gas production as of July 31, 1988 was 8.1033387 x 10^{11} m^3 (28,613,484 mcf) (St. Peter, pers. com., 1988).

6 THE STONEY CREEK OIL AND GAS FIELD

6.1 Data Acquisition, Manipulation and Presentation

The geology of the Stoney Creek Oil and Gas Field is interpreted from lithologic well logs developed from ditch cuttings stored at the New Brunswick Department of Natural Resources and Energy, Fredericton, New Brunswick and from data on preexisting drill logs. Thirty-one wells from Stoney Creek were relogged. The new data were stored in LOTUS 123 WKS and PIC files and illustrated on graphic logs presented in the New Brunswick Department of Natural Resources and Energy standard lithologic well log format (Appendix A). The wells relogged include: New Brunswick Gas and Oilfields Ltd. 62, 68, 73, 80, 83, 84, 91, 97, 109, 113, 114, 121, 126, 128, 131, 133, 134, 137, 138, 140, 144, 145, 147, 148, 149, and New Brunswick Oilfields Ltd. 153, 156, 157, 158, 161 and 163 (Plates 88-158(R) to 88-188(R). Three wells completed in 1985 were also added to the data base. These include Irving Oil Ltd / Chevron Canada Resources Ltd., Stoney Creek No. 1, East Stoney Creek No. 1, and Hillsborough No. 1 (locations 1, 2 and 3 respectively, Figure 1).

On the graphic logs (Plates 88-158(R) to 88-188(R), in pocket), oil shales are ranked qualitatively as low, medium or high grade. The grade was estimated from the chip samples using an alcohol burner. A low grade rank was assigned to those shales which turned black, produced a small flame and began to smoke with a petroliferous odour. A medium grade was assigned to those shales which ignited with relative ease and began to smoke with a petroliferous odour. A high grade was given to shales which ignited quickly in the lamp flame and burned freely outside the flame.

Many of the coarse-grained to granular sandstones are represented in the ditch cuttings as individual sand grains or clasts devoid of any apparent matrix or cement. On the graphic logs this property is described as "disaggregated". The disaggregation may reflect leaching of the cements, or it may be purely a result of physical disintegration of the cement by the old percussion drilling method. It is worth noting that the sandstones from the recent Irving/Chevron wells are not disaggregated.

Lithologic descriptions are presented on the graphic logs in the New Brunswick Department of Natural Resources and Energy abbreviation format (Appendix A). The following is an example of a typical sandstone description over depth X: hi disagg calca pbly qtzaren; 10% ls; mnr sh. This description translates to: Depth X is dominated by highly disaggregated calcareous pebbly quartzarenite. In addition the logged interval contains 10 percent limestone and a minor component of shale. The following is an example of a typical mudstone description over depth X: 40% med/hi & 10% med/low grd ker sh; 10% mgss; mnr vn calc. This description translates to: Depth X is dominated by shale, 40 percent of which is medium to high grade kerogenous shale and 10 percent is medium to low grade kerogenous. In addition the logged interval contains 10 percent medium-grained sandstone and minor vein calcite.

Sandstone porosity in the oil and gas field ranges up to 20 percent but permeability is less than 100 md. A conservative estimate suggests that secondary porosity constitutes almost half of the total porosity. Secondary porosity is caused by dissolution of feldspars, carbonates and clays. Interstitial chlorite porosity probably ranges up to 2 percent (Chowdhury, 1988).

The well log data were utilized to construct cross-sections through the oil field (Figures 5-13). The cross-sections illustrate the interpreted distribution of unconformities, the orientation and movement on faults and the major sandstone and shale zones within the Albert Formation. Seismic reflection profiles were used to supplement the well log data and enhance the cross-section interpretations. The index map (Figure 4) illustrates the location of each cross-section as well as those wells presently producing oil or gas.

Two-dimensional data presented on the cross-sections were used to construct structural contour maps and isopach maps of the Stoney Creek Oil and Gas Field (Figures 14-19). This data was also used to create three-dimensional surface models of the Enragé Unconformity (see definition below) and of the major correlatable sandstone and shale zones within the Albert Formation (Figures 20-35, Appendix B). This was accomplished by utilizing a two- and three-dimensional graphics software program, Surfer (Golden Software, Inc.). Well data extracted from the

cross-sections were used in Surfer to create structural contour maps (Figures 21, 24, 27, 30 and 33, Appendix B) and complementary three-dimensional raised contour maps (Figures 22, 25, 28, 31 and 34, Appendix B) and gridded surfaces (Figures 23, 26, 29, 32 and 35, Appendix B).

6.2 Cross-Sections Interpretation

Nine cross-sections were constructed through the Stoney Creek Oil and Gas Field. Four of those sections are oriented north-south (Figures 5-8); five are oriented east-west (Figures 9-13). A major unconformity occurs within the stratigraphic section throughout the field. The unconformity lies between the Upper Devonian / Lower Carboniferous Horton Group and the overlying Upper Carboniferous Enragé Formation. For ease of description this feature is called the Enragé Unconformity. Two formations lie above the unconformity in the Stoney Creek area and include, in ascending order, the Enragé and Boss Point formations. Three formations of the Horton Group lie below the unconformity and include, in descending order, the Moncton, Albert and Memramcook formations. The Horton Group thickens to the south as a clastic wedge between the underlying basement complex and the overlying Enragé Unconformity (Figures 5-8). The strata dip to the south at approximately 15 degrees. Sandstone within the Albert Formation constitutes a greater part of the section downdip to the south. The sandstone zones progressively thin out laterally to the east and west.

A coarse-grained proximal facies containing a dominant plutonic detrital fraction is recognized in the upper Horton section along the western margin of the field (see graphic logs for wells 97, 114, 156, 157 and 161 (Plates 88-165(R), 88-168(R), 88-184(R), 88-185(R) and 88-187(R) and Figures 5, 9, 10, 11, 12 in pocket). These conglomerates were initially interpreted as a proximal facies of the Albert Formation, but seismic profiles across the western margin of the field reveal the presence of an angular discordance at the base of this unit. The discordance is believed to be an unconformity, the same Hillsborough Unconformity which Gussow (1953) described as lying between the Weldon and overlying Hillsborough formations (i.e., members of present usage). The unconformity appears to be restricted to the western margin of the oil field. Throughout the remainder of the field the Hillsborough unconformity has been eroded by a later event which formed the Enragé Unconformity.

The Albert Formation sandstones within the Stoney Creek Oil and Gas Field have been subdivided into three correlatable zones (Figures 5-13). The zones consist of a series of interbedded sandstones, siltstones and mudstones. Each zone is separated from the other by intervening mudstone units. The term sandstone zone may be slightly misleading. The proportion of sandstone within each zone varies substantially across the field. In some sections mudstone dominates the zone. The highest concentration of sandstone occurs towards the centre and southern margins of the oil and gas field. Toward the east and west the sandstone content within each zone decreases noticeably. A high grade oil shale zone defined as the Frederick Brook Member by Greiner (1962) is a laterally continuous marker within the field. It facilitates correlation of zones particularly across faults.

Drillers developed a correlation scheme at Stoney Creek which was based on the occurrence of six workable divisions within the Albert Formation and which they referred to as "driller's sands" (Figure 2). "Driller's sand 5" corresponds to the high grade oil shale described above. Howie (1968, 1979) applied the "driller's sand" terminology in his work on the oil field. It is difficult, however to extrapolate and correlate the "driller's sands" with any degree of confidence, with the exception of "driller's sand 5". Individual sandstone bodies appear to be discontinuous and lenticular. Henderson (1940) also recognized the discontinuity of the sandstones. He indicated that the original spacing of the wells, which varied from 300 to 800 m, was found to be too great and the drilling of intermediate wells discovered intact highly productive sandstones under their original pressure.

Faults were interpreted from the apparent offset of strata within the oil and gas field. The location of these faults is illustrated on the cross-sections (Figures 5-13) and on the structural contour maps (Figures 14-17). Descriptions and notes on the original driller logs were utilized in interpreting the faults.

It is evident from the driller logs that drilling became difficult through structurally disrupted sections. Although the driller logs do not indicate the intersection of faults, faults can be interpreted from the driller's notes which describe related drilling problems. Ditch cuttings obtained from structurally disrupted zones tend to be dominated by shale. The increase in shale in these samples probably resulted from caving and mass contamination. Obvious problems arose in the drilling of many of the earlier wells, as noted on the driller logs. The original data from those wells must be interpreted with caution.

A major fault cuts the southern part of the oil field immediately south of New Brunswick Gas And Oilfield Ltd. well numbers 97, 87, 141, 149, 142 and New Brunswick Oilfields Ltd. well number P5 (Figures 6, 7, 10 and 12). The fault dips to the south with a south-side-down component of movement. The Boyd Creek Tuff of the Moncton Formation is preserved in the hanging wall block to the south. A coarse-grained conglomeratic facies of the Hillsborough Member, similar to that which occurs along the western flank of the oil and gas field is also preserved in the hanging wall block (see the graphic logs of wells number 126, 128, 140 on Plates 88-170(R), 88-171(R) and 88-177(R), in pocket, and Figures 6, 7, 10, and 12). This fault is interpreted as a listric normal fault from seismic profiles.

Two parallel faults are interpreted from the sections crossing the northeast part of the field (Figures 7, 8, 11 and 13). The two faults strike northwest - southeast (Figure 14-17). The more eastern fault appears to be a high-angle reverse fault with a down-to-the-west sense of movement. The more western fault appears to be a normal fault with a down-to-the-east sense of movement. Displacement on the two faults has isolated a thicker section of Horton rocks in the intervening graben structure. The increase in thickness in this section suggests that the faults were active during sedimentation. They were probably long-lived and controlled by basement structure. The apparent reverse displacement on the eastern fault is probably a reactivation of an earlier normal fault. A northeast-southwest-trending fault is interpreted in the northwest part of the field (Figures 5, 10, 11 and 14-17). Control on this fault is limited and therefore the exact position is tenuous. It appears to be a normal fault with a down-to-the-east sense of movement.

6.3 Structural Contour and Isopach Map Interpretation

Structural contour maps were constructed for the top of sandstone zone 1, sandstone zone 2, the Frederick Brook Member and sandstone zone 3 (Figures 14-17). Faults interpreted from the cross-sections are illustrated on each of these maps. Each map closely complements the other and all reflect the stratigraphic continuity within the field. The western two thirds of the oil field appear to have been relatively structurally undisturbed. Henderson (1940) also recognized the continuity within the Albert section in the west. Each zone dips uniformly to the south. The eastern portion of the field is obviously structurally more complex. The strata have been folded into a doubly plunging syncline with its axis oriented northeast-southwest. The faults affecting that area have offset the strata with a normal or high-angle reverse sense of movement. The faults may be basement controlled and were ultimately responsible for the development of the synclinal structure.

The continuity of the structural contours crossing the east-west fault which cuts the southern margin of the oil and gas field, indicates that the magnitude of displacement on that fault is not large. The fault may have developed as a growth structure during Horton deposition.

Isopach maps were constructed for sandstone zone 2 and the Frederick Brook Member oil shale (Figures 18 and 19). The isopachs indicate that the sandstone and oil shale units thicken in what appears to have been local depressions. The most obvious depression is located in the central-eastern region of the oil field and coincides with the syncline structure as evident by comparing the isopach maps with the structural contour maps (Figures 14-17). Thickening of the sediments within the syncline further indicates that the structure was syndepositional and basement controlled. The similar spatial and thickness distribution of sandstone zone 2 and the oil shale zone may indicate that the sands were reworked by shoreline processes and concentrated within

local basins.

6.4 Three-Dimensional Computer Model Interpretation

Five surfaces were modeled using three-dimensional grid software (Surfer). These include the Enragé Unconformity and the tops of sandstone zone 1, sandstone zone 2, sandstone zone 3 and the Frederick Brook Member. A grid was superimposed over the oil and gas field. The north-south direction was zeroed on New Brunswick Gas and Oilfields Limited Well No. 126 in the south. The east-west direction was zeroed on Maritime Oilfield Limited Well No. 37 in the west (Figure 20, Appendix B). Initially, structural contour maps were developed for each grid surface (Figures 21, 24, 27, 30 and 33, Appendix B). The contour maps differ from those described in the above section in that the contour maps described here do not consider the effects of faulting. The faults are plotted on the computer two-dimensional contour maps but are not taken into account when the computer contours are generated.

The gridded surfaces (Figures 23, 26, 29, 32 and 35, Appendix B) display the internal geometry of the oil and gas field very well. The locations of the wells used in the construction of the grid surfaces are plotted on the contour maps. As evident from the data, the geometry of the grid surfaces on the margins of the field are poorly constrained, although the central body of the grid is well defined.

A consistent feature apparent on all plots is a lineament in the northeast corner of the grid which extends as a ridge from the north-central part to the east-central part of the field. The lineament coincides with the fault system which was interpreted for the same area and is illustrated on both the computer-generated contour maps (Figures 21, 24, 27, 30, and 33, Appendix B) and the interpreted contour maps of Figures 14-17.

6.5 Hydrocarbon Trapping Mechanisms

It has been known for many years that the main producing oil zone is sandstone zone 3 ("driller's sand 6") immediately below the Frederick Brook Member. The main producing gas zone is sandstone zone 2 ("driller's sands 3 and 4") immediately above the Frederick Brook Member (Henderson, 1940; Howie, 1968). The present oil and gas producing wells have been plotted on the three-dimensional raised contour diagrams of sandstone zone 2 (Figure 28) and sandstone zone 3 (Figure 34) and on Figure 4. Henderson (1940) believed that a north-south-striking thrust fault divided the productive area into an eastern and western section and he used this fault to account for the distribution of oil and gas. The present data strongly suggests stratigraphic continuity across this zone and challenges the validity of Henderson's fault interpretation.

One known oil producing structure is closely associated with the prominent fault cutting the south margin of the field. The structure is a rollover anticline on the south or hanging wall blocks. It is obvious on seismic sections. The producing wells from this structure include New Brunswick Gas and Oilfields Well No. 106 with its photogenic pump jack visible on the east side of Highway 114.

A large number of producing gas wells have been drilled in the structurally more complex eastern part of the field. It is difficult to delineate the trapping mechanism but structure is more than likely involved.

Many gas wells occur in the area of stratigraphic continuity in the western part of the field. The hydrocarbon traps in this area are undoubtedly stratigraphically controlled updip pinch-outs. The producing gas sands in this area may be restricted in the west by the fault which cuts the west margin of the oil and gas field (Figures 14-17).

6.6 Provenance of the Stoney Creek Sands

The arkosic composition and geometry of the sandstone beds at the Stoney Creek Oil and Gas Field have been used in the past as evidence to indicate that the clastics in the eastern Moncton Subbasin were derived from a southern source area (Howie, 1968, 1979; Pickerill and Carter, 1980). The Albert Formation at Stoney Creek as described previously thickens to the south away from the Westmorland Uplift and sandstones shale-out to the north. This indicates that the Westmorland Uplift immediately north of the field could not have been the source area for these sands. Howie (1968, 1979) recognized this and postulated the provenance of the Stoney Creek sandstones to be south of the Minas Basin in Nova Scotia.

Howie (1979) and Carter and Pickerill (1980) expanded this conclusion to imply that the Westmorland Uplift was therefore a post-Carboniferous structure. Many authors have cited the work of Gussow (1953) to support this hypothesis, but in fact this is a complete misinterpretation of what Gussow has said. He stated that the buried Westmorland Uplift was positive during only part of the Carboniferous period (Gussow, 1953, p. 1796). Gussow qualifies this statement (Gussow 1953, p. 1769) by indicating that the surface anticline, which is coincident with the surface axis of the Westmorland Uplift, appears to be an original structure formed by overlapping of younger (Pennsylvanian) formations onto the pre-existing structural-topographic high. Gussow therefore believed the Westmorland structure was inactive during the Pennsylvanian but that it may have been an active source area during the Late Devonian and Mississippian, in contrast to what later authors have written. Gussow (1953, p. 1796) stated that he considered both the Caledonia Uplift and the Westmorland Uplift to be positive features during the Mississippian.

Seismic profiles (Chevron Canada Resources Limited) across the Stoney Creek area indicate that the thickness of the Horton section at Stoney Creek is controlled by the Westmorland Uplift. The Westmorland basement / Albert Formation contact is for the most part unfaulted and the Albert Formation onlaps the basement to the north. The uplift directly north of the oil and gas field apparently acted as a passive barrier and did not supply sediment directly to the south. Seismic sections east of the Petitcodiac River display a faulted yet relatively continuous Horton section dipping southwest away from the Memramcook East Fault (Figure 1).

The distribution and facies geometry of the Memramcook Formation appears to be controlled by local highlands. The highlands also control the basin geometry. This implies that the Memramcook exposed along the Caledonia Uplift was sourced from the Caledonia Uplift and the Memramcook exposed in the type locality at Stoney Creek south of Calhoun was sourced from the Westmorland Uplift.

The Memramcook Formation exposed in the type locality at Stoney Creek supports a Westmorland source. An obvious facies change from coarse fanglomerates to sandstones and shales occurs from north to south off the highlands (Norman, 1941a, 1941b; St. Peter, pers. com., 1988). Lithologic studies by McLeod and Ruitenberg (1978) and St. Peter (unpublished data) indicate a polymictic assemblage of clast types, including granitoid, felsic and mafic volcanics, metamorphic and sedimentary rocks. The polymictic nature of the clasts within the Memramcook Formation is an indication that the lithologic character of the Westmorland Uplift is not the simple granitic terrane it is usually assumed to be, but that it more likely consists of a mixed assemblage resembling closely that seen in the Caledonia Uplift.

The location of the Sackville Subbasin to the southeast of the Moncton Subbasin and the seismic evidence which suggests that the Sackville Subbasin contains a thick Horton section, places serious limitations on the provenance of sediments in the Stoney Creek field. If it is assumed that these sediments were derived from Nova Scotia, as suggested by Howie (1979) and Pickerill and Carter (1980), then they would have to have been transported across the obvious depocentre in the Sackville Subbasin and up the paleoslope on the north side of the Hillsborough Subbasin, which is highly unlikely.

It is concluded here that the source of the sands at Stoney Creek was not to the south, as previously supposed, but from a more local eastern source - the Westmorland Uplift. This is further supported by the paleocurrent measurements plotted on Figure 3, which indicate a dominant westerly transport direction. Stoney Creek represents a facies play against a passive segment of the Westmorland Uplift.

7 REGIONAL SEDIMENTOLOGICAL AND TECTONIC IMPLICATIONS

The origin of the Moncton Subbasin has puzzled geologists for some time. One of the main deterents to developing a definitive tectonic model is the lack of understanding on magnitude, sense, and timing of movement on the basin-controlling faults. A more complete understanding of the tectonics of the Moncton Subbasin may be possible by comparing and associating its structural and sedimentological elements with those in the Sackville Subbasin to the southeast (Figure 1).

The geometry and tectonic style of the Sackville Subbasin has recently been established primarily on the basis of seismic reflection profiles (Martel, 1987). The seismic evidence of the Sackville Subbasin supports a regional strike-slip origin as formerly proposed by Webb (1963, 1969) and Bradley (1982). The basin appears to have formed under a regional transtensional regime which culminated in major dip-slip and strike-slip movement along regional faults.

The Sackville Subbasin appears similar to the Moncton Subbasin in size, structure and stratigraphy, which together with their proximity suggest a similar origin. Martel's (1987) tectonic model of the Sackville Subbasin can therefore be expanded to encompass the Moncton Subbasin.

Figure 36 illustrates the simplistic tectonic arrangement of the basement structures which are responsible for basin geometry. As originally stated by Martel (1987), the Sackville Subbasin developed in an en echelon relationship with the Moncton Subbasin and probably represents the beginning of basin coalescence as described by Aydin and Nur (1982).

The Westmorland basement complex has previously been considered a post-Hortonian uplift and consequently had no effect on Horton sediment distribution. Recent seismic information disputes this hypothesis and has revealed the importance of the Westmorland Uplift as a basin-controlling feature. Martel (1987) stresses the importance of the Westmorland basement as a dominant provenance region. He believes that the Dorchester Fault (Figures 1 and 36), which marks the contact between the Sackville Subbasin and the Westmorland Block to the north, has a very large throw. The Dorchester Fault accommodated much of the subsidence in the Sackville Subbasin producing a thick wedge of Horton sediments along its northern margin.

A system of north-south-striking normal faults with down-to-the-east offsets occur off the eastern end of the Caledonia Uplift. A coarse fanglomerate facies which fines to the east off the fault blocks attests to the activeness of the fault system during deposition of the Horton Group (St. Peter, pers. com., 1988). The Memramcook River Fault (Martel, 1987) is associated with this fault series and restricts the Sackville Subbasin on its western margin (Figures 1 and 36).

A system of east-west faults has been mapped in the region of coalescence between the Moncton and Sackville subbasins. The faults include the Peck Creek, Hillsborough and Salem faults of Gussow (1953) and the Boudreau Fault of St. Peter (1982) (Figures 1 and 3). The fault system is genetically related to basin-controlling faults that restrict the Moncton Subbasin along the Caledonia Uplift and the Sackville Subbasin along the Westmorland Uplift (Figures 1 and 36). The effects of faulting in this area are observed in the Pennsylvanian cover but become much more pronounced in the older Mississippian rocks (St. Peter, pers. com., 1988). Fault movement appears to have been long lived and the effects of deformation are progressively stronger in older strata. The intersecting network of north-south normal faults and east-west strike-slip faults attests to the tectonically complicated nature of the zone between the Moncton and Sackville subbasins.

With the aid of high-resolution seismic profiles, the knowledge of sedimentary facies distributions and fault tectonics, a pull-apart basin model is herein proposed. The Moncton Subbasin is believed to have formed as a pull-apart basin in a dextral strike-slip regime. Source terranes were local and strike-slip displacement on the east-west fault systems were probably in the order of 10 to 20 km.

The documented occurrence of thrust components on many of the fault systems (Gussow, 1953; McCutcheon, 1981; Ruitenberg and McCutcheon, 1982, and others) and the apparent orientation of younger fold structures parallel to regional northeast-southwest striking faults (Webb, 1963, 1969;

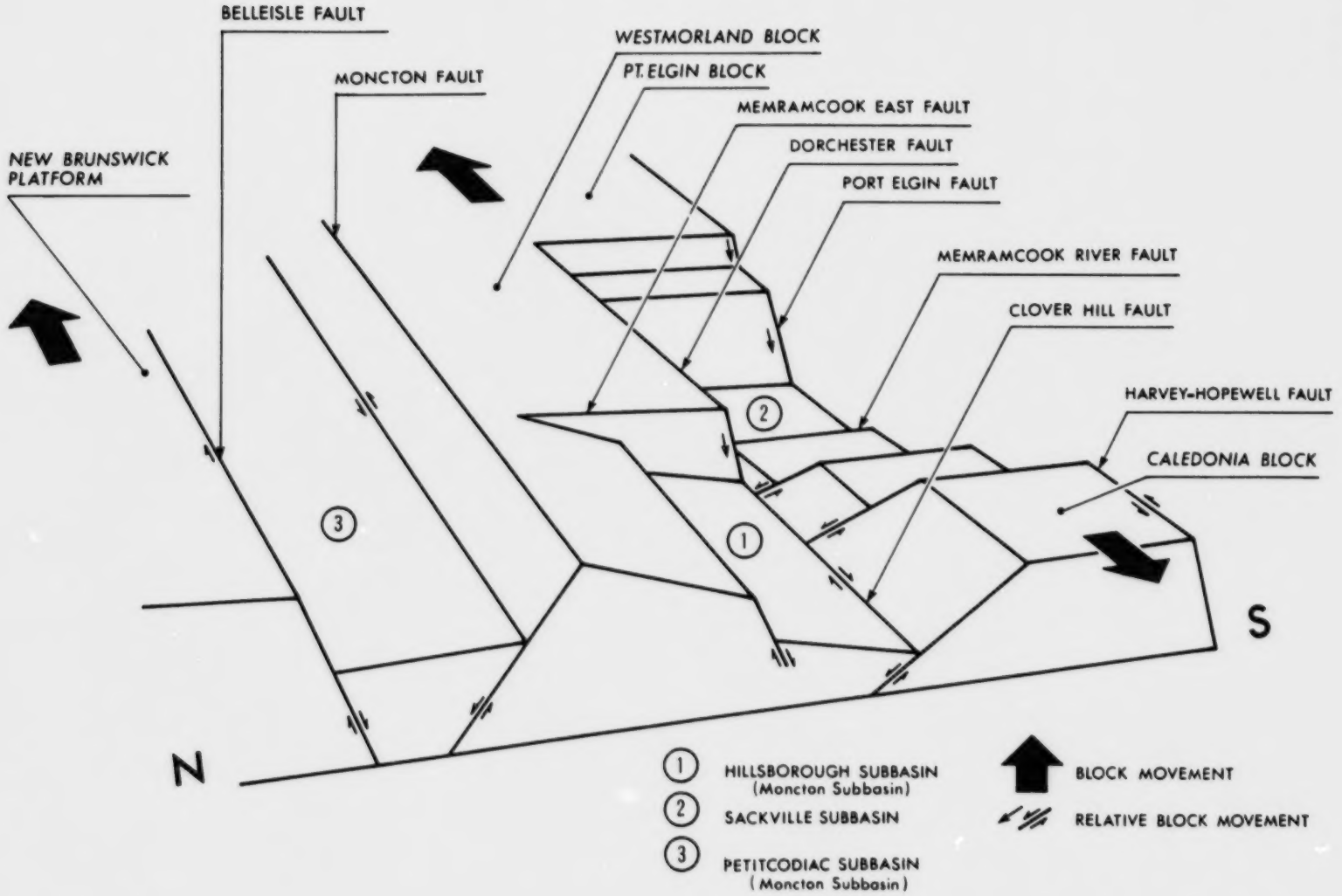


Figure 36: Regional tectonic model illustrating the distribution of basement faults which controlled the geometry of the eastern Moncton Subbasin and Sackville Subbasin

Bradley, 1982; Ruitenberg and McCutcheon, 1982) have been presented as evidence which contests the application of a strike-slip model.

The high drag concept of wrench tectonics is characterized by the development of en echelon folds within the zone of transcurrent deformation (Harding, 1976, Howell et al., 1980; Reading, 1980). In the early stages of wrenching the principle stress direction, σ_1, is expected to be oriented perpendicular to the primary fold axis (Figure 37a) (Harding, 1976; Reading, 1980). Through time, as faulting continues, the folds are progressively rotated into parallelism with the strike-slip direction (Reading, 1980; Mount and Suppe, 1987). In contrast, younger folds developed within many well documented wrench systems are oriented almost parallel to the principle slip direction. These include the classic example of active wrench tectonics, the San Andreas Fault (Mount and Suppe, 1987).

In recent studies the conceptualized standard strike-slip tectonic models have been revisited. It is now believed that the San Andreas Fault moves on a nearly frictionless surface. With time there has been a decoupling along the fault system resulting in a drop in shear stress. This has caused the rotation of the principle stress direction, σ_1 (Figure 37b) (Mount and Suppe, 1987). Wrenching appears to be accommodated along a narrow zone (< 3-10 km) of pure strike-slip. The regional compressive stress applied by the Coastal and Transverse ranges is accommodated in a wide (50-100 km) zone of thrust faults and related fault bend anticlines (Mount and Suppe, 1987).

In New Brunswick, a rotation of the principle stress direction during the Carboniferous was documented by Webb (1963, 1969). The stress field rotation may very well be accounted for by the application of a low drag decoupling as in the model suggested by Mount and Suppe (1987).

7.1 Implications with Respect to Regional Facies

The tectonic setting and regional Albert Formation facies geometry (referred to below) are interpreted in Figures 36 and 38 respectively. The spatial distribution of the facies is not well understood. However, it is fairly well constrained in the vicinity of the Caledonia Uplift. Large alluvial fans formed off the highlands along the south side of the Hillsborough Subbasin (Gussow, 1953; Greiner, 1962, 1974; McCutcheon, 1978; McLeod, 1980; Pickerill and Carter, 1980; St. Peter, 1982; Pickerill et al., 1985; Carter and Pickerill, 1985a, 1985b). The axis of the Hillsborough Subbasin was occupied by an extensive lake (Gussow, 1953; Greiner, 1962, 1974; Pickerill and Carter, 1980; St. Peter, 1982; Pickerill et al., 1985; Carter and Pickerill, 1985a, 1985b) or system of lakes (Chowdhury, 1988) during Albert time. On the north margin of the Hillsborough Subbasin in the present vicinity of the Stoney Creek Oil and Gas Field sediments were being deposited in a passive marginal lacustrine shoreface environment. Farther east of Stoney Creek, fluvial systems carried sediment off the Westmorland Uplift eventually depositing their load in the basin as small lacustrine deltas.

The Albert Formation sandstones at Stoney Creek have always been described as arkosic, and therefore it is assumed that the source was granitic (Howie, 1979; Pickerill and Carter, 1980). Recent petrographic studies by Chowdhury (1988) have indicated a small but significant volcanogenic detrital component in these sandstones. The coarse-grained clastics of the Memramcook Formation, in the type locality along the Westmorland Uplift (McLeod and Ruitenberg, 1978; St. Peter, unpublished data), are polymictic. As indicated previously, the Westmorland Uplift is more likely a Coldbrook type terrane, and not a predominantly granite terrane as previously assumed. In this regard the arkosic lithology of the sandstones at Stoney Creek is probably not so much a reflection of a granitic source but rather a response to the sedimentologic and tectonic environment. The fluvial systems draining the Westmorland Uplift were debouching from a hinged margin (Figure 38). Consequently the rivers had a lower gradient than those along the faulted Caledonia Uplift. As a consequence the resulting sandstones are more mature at Stoney Creek.

Irving Oil Limited / Chevron Canada Resources Limited Hillsborough No. 1, located 4.7 km south of the oil field (location 3, Figure 1), was drilled to a depth of 3013 m. The top of the Albert Formation was intersected at a depth of 1320 m. The upper 800 m of Albert section correlates very well with the sequence at Stoney Creek (Figure 39). The lower 900 m in the Hillsborough well is

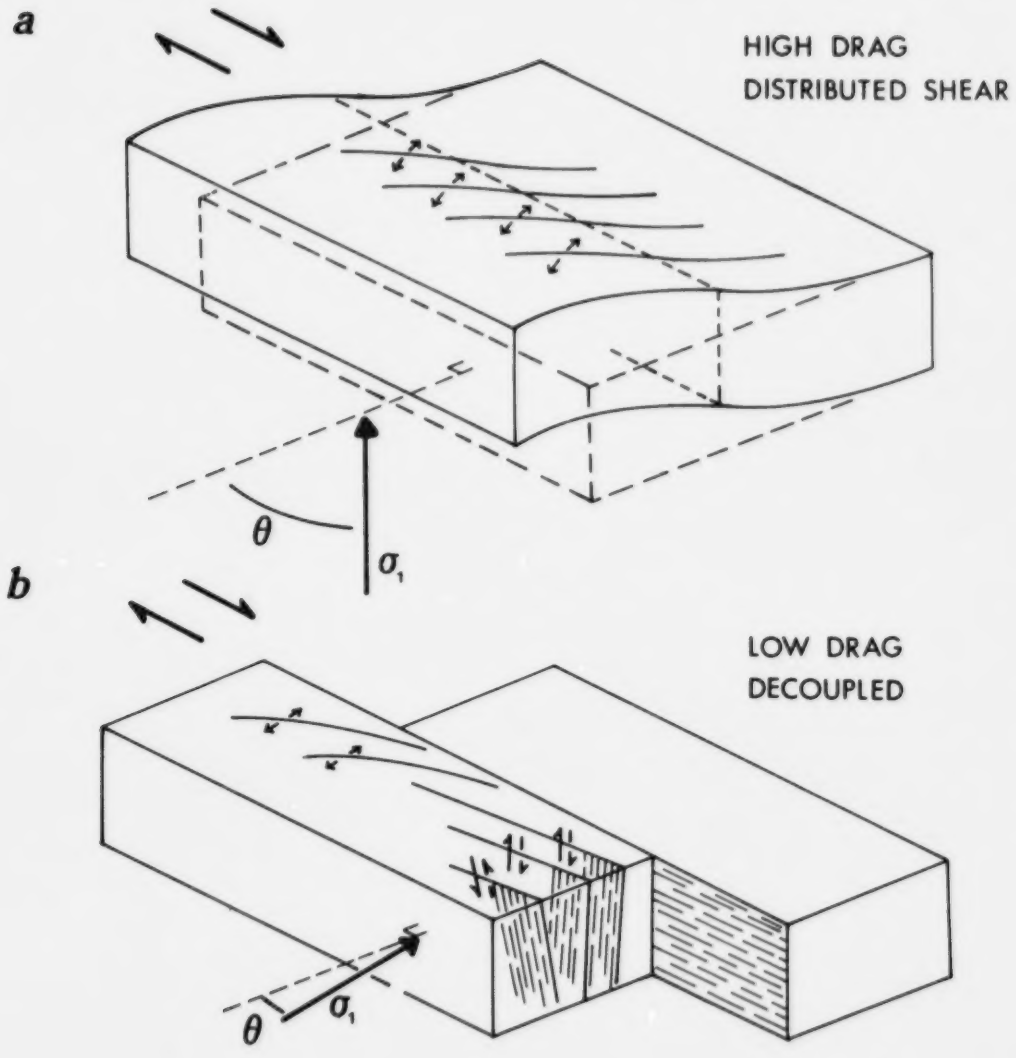


Figure 37. a: Deformation style predicted by distributed-shear high drag concepts of wrench tectonics. Angle (θ) between the principle stress direction (σ_1) and the normal to the fault is 30-45 degrees. b: Deformation style predicted for decoupled transcurrent and thrust deformation along a low drag wrench fault having little distributed shear. Angle (θ) between the principle stress direction (σ_1) and the normal to the fault is small (modified after Mount and Suppe, 1987).

very different from anything observed within the oil field. This part of the section is dominated by sandstone. Some units reach thicknesses of 200 m. The sandstones appear to have accumulated as thick fluvial deposits. During the early stages of basin formation, fluvial systems must have occupied the axial part of the basin. As subsidence continued the river systems retreated to the basin margins and the deeper axial part of the basin became occupied by a lake. The thick basal sandstones present in the Hillsborough No. 1 well represent the remnants of early axial fluvial deposits.

On the north side of the Westmorland Uplift a northern arm of the Moncton Subbasin, the Petitcodiac Subbasin, was concurrently being filled by thick clastic sequences. Very little is known about the history of Horton Group sedimentation within the Petitcodiac Subbasin. Almost the entire Horton section is overlain by a blanket of Pennsylvanian sediments. The only exposed Albert Formation is in the Indian Mountain Uplift (Figure 1). The formation here is dominated by a thick sequence of dolomitic shales and siltstones containing evidence of subaerial exposure and is characteristic of a carbonate mudflat environment (Pickerill et al., 1985; Carter and Pickerill, 1985a). In the past this exposed sequence has been interpreted as representing the only facies, and environment of deposition within the Albert in the Petitcodiac Subbasin. Contrasting evidence is shown from seismic profiles which indicate that a thick pile of Horton sediments may contain a coarse clastic facies adjacent to the Westmorland Uplift in the south and possibly adjacent to the New Brunswick Platform in the north. The exposed Albert Formation at Indian Mountain may have biased previous assessments of facies and environments within the Petitcodiac Subbasin.

The Mississippian section within the Sackville Subbasin is completely obscured by the Pennsylvanian sedimentary cover. Our only clue to the type of Horton Group section is revealed through seismic data. Martel (1987) has interpreted what he believes to be the upper and lower Windsor Group reflectors. Underlying the lower Windsor Group reflector is a thick sequence of probable Horton Group rocks. The geometry and tectonic style of the basin as revealed by the seismic data appear to have been favourable for the accumulation of thick coarse clastic sequences. The deposits within the Sackville Subbasin may closely resemble those within the Moncton Subbasin.

7.2 Reevaluation of the Hydrocarbon Potential in Southeastern New Brunswick

There is little potential for an increase in hydrocarbon production at Stoney Creek. Engineering and geological mismanagement over the years have made the possibility of any substantial secondary recovery unlikely. The importance of Stoney Creek does not lie in its remaining potential as a hydrocarbon producer but in its importance as an aid to understanding the sedimentary and tectonic environments which controlled the field. This can contribute to more knowledgeable exploration elsewhere in the basin.

The sedimentologic and tectonic model advanced above would suggest that the Stoney Creek reservoir is not unique. It appears to be just one of many potential similar plays. Stoney Creek represents a stratigraphically and structurally controlled reservoir updip along the margin of a passive segment of the Westmorland Uplift. There exists a real potential for similar plays along strike from Stoney Creek. The area presenting the best potential lies east of the Petitcodiac River. The thickest sandstones should occur down dip to the south of the uplift. The reservoirs will probably be deep, in the order of 1500 to 3000 m and the reservoir quality will depend very much on structure and the amount and distribution of secondary porosity and permeability. The area of exploration in the Hillsborough Subbasin will be restricted in the east by the Memramcook East Fault (Figure 1). Deep reservoirs may also occur south of Stoney Creek at depths of 2000 m and more in the fluvial sequences. Again reservoir quality will depend a great deal on structure and secondary porosity.

There exist in southeast New Brunswick several areas which have been virtually untested. Their potential is unknown but preliminary evidence certainly would suggest taking a closer look. The two main areas in question are the Sackville Subbasin and the Petitcodiac Subbasin. Preliminary work in both basins suggests the occurrence of thick sections of coarse Horton Group clastics along basin margin faults. Excellent source rocks

occur in the Petitcodiac Subbasin where kerogenous shales of the Albert Formation are exposed at Indian Mountain. Similar source rocks are likely present in the Sackville Subbasin. Martel 1987) has recently emphasized the exploration potential in the Sackville structure.

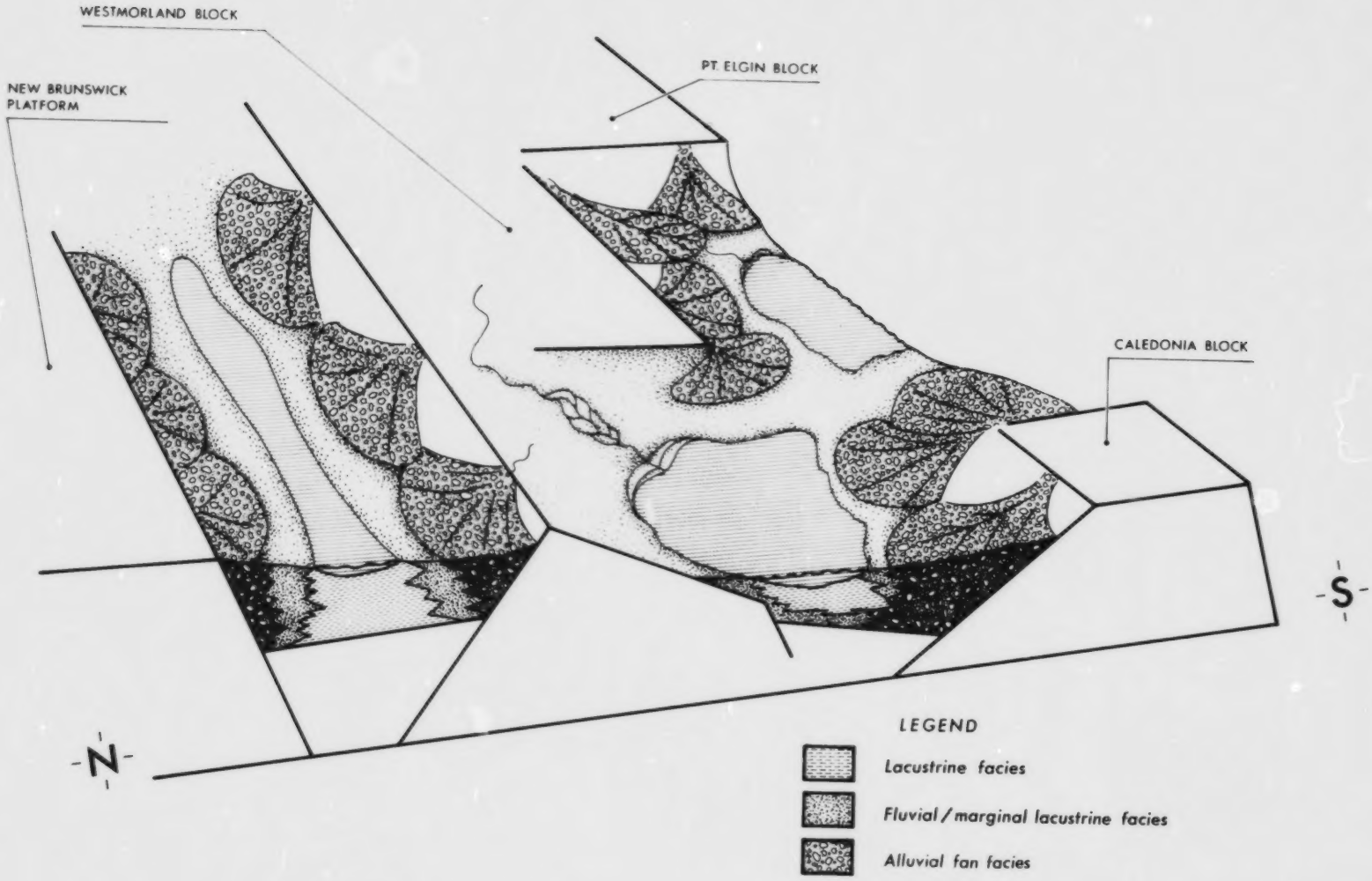


Figure 38: Regional facies distributions within the eastern Moncton Subbasin and Sackville Subbasin (refer to Figure 36 for fault geometry).

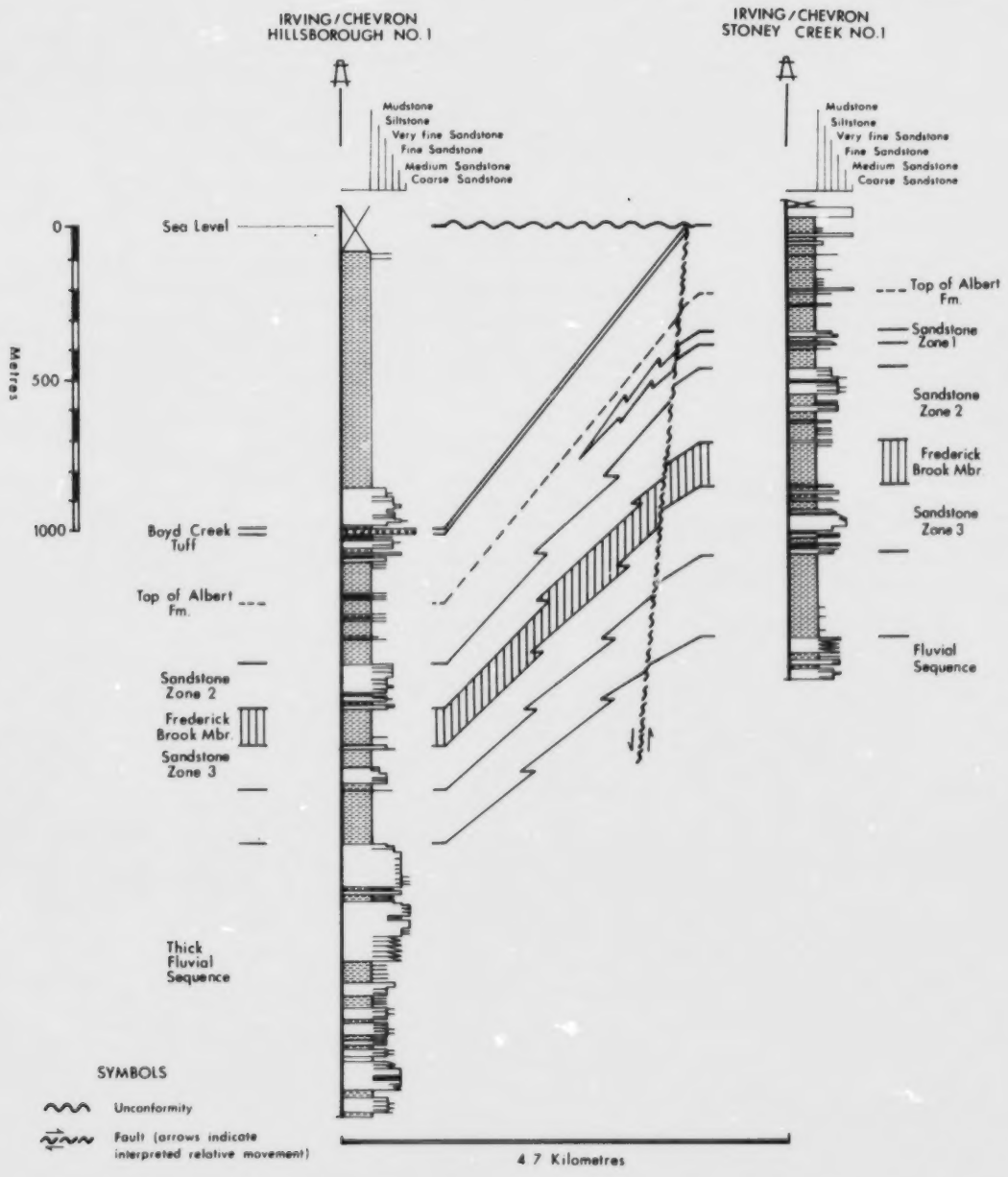


Figure 39: Geological correlation diagram for Irving/Chevron Stoney Creek No. 1 well and Irving/Chevron Hillsborough No. 1 well (for the classification of zones refer to Figures 5-13).

8 CONCLUSIONS

1. The Horton Group sequence within the Stoney Creek Oil and Gas Field is an onlapping deposit along a passive segment of the Westmorland Uplift.

2. The interbedded sandstones, siltstones and mudstones of the Albert Formation, in the vicinity of the Stoney Creek Oil and Gas Field dip and thicken to the south as a clastic wedge between the underlying Memramcook Formation and Westmorland basement complex and the overlying Moncton Formation and Enragé Unconformity.

3. The Albert Formation within the Stoney Creek Oil and Gas Field can be and is herein subdivided into three distinct laterally continuous sandstone zones and one laterally continuous high grade oil shale zone (Frederick Brook Member).

4. The marginal lacustrine sands and muds deposited within the Stoney Creek Oil and Gas Field are thickest within basement-controlled depressions.

5. High resolution seismic profiles, facies distribution and paleocurrent data indicate that the sediments deposited at Stoney Creek and in the northeastern part of the Hillsborough Subbasin were derived from the Westmorland Uplift to the east.

6. The thick sandstone succession observed at the base of the Irving Oil Limited \ Chevron Canada Resources Limited Hillsborough No. 1 well was probably deposited as a fluvial sequence, probably derived from the east, which initially filled in the axis of the basin prior to the establishment of the Albert lacustrine environment.

7. Hydrocarbon traps within the oil field are both structurally and stratigraphically controlled. A prominent normal fault displaces the Albert sequence along the south margin of the oil field. Some hydrocarbons have been trapped in a rollover anticline associated with the southern downthrown block. In the central-eastern part of the field hydrocarbons are trapped within a structurally complex zone closely associated with a prominent depositional depression. A productive natural gas zone occupying the western half of the field is stratigraphically controlled in updip pinchouts.

8. Evidence presented herein suggests a close tectonic relationship between the Moncton Subbasin and the Sackville Subbasin which lies to the southeast.

9. The Moncton and Sackville subbasins are interpreted to have developed synchronously as en echelon depocentres in response to right-lateral strike-slip tectonics.

10. The Westmorland and the Caledonia uplifts were prominent local source areas for Horton Group detritus in both the Moncton and Sackville subbasins.

11. The southern arm of the Moncton Subbasin - the Hillsborough Subbasin is restricted in the east by the Memramcook East Fault.

12. The prominent Moncton Fault restricts the northern arm of the Moncton Subbasin - the Petitcodiac Subbasin - on its southern margin against the Westmorland Uplift. Seismic profiles which cross the fault indicate a large component of normal movement with a north-side-down displacement.

13. From this study of the geology of the Stoney Creek Oil and Gas Field and the regional structural geometry and facies distributions within the Hillsborough Subbasin, it is believed that the most promising areas of hydrocarbon exploration occur along strike and downdip from the Stoney Creek field.

14. Thick Horton Group sequences are indicated for both the Petitcodiac and Sackville subbasins and therefore these basins may prove to be successful wildcat targets.

9 RECOMMENDATIONS FOR FURTHER WORK

The long term licenses which covered much of the potential oil-bearing rocks in New Brunswick have recently lapsed and the land held under those licenses has reverted to the Crown. The release of this land should motivate interest in further exploration. In order to further this interest additional grassroot studies are required.

More work is needed in order to determine the magnitude, sense and timing of displacement on the regional fault systems which control basin geometry and subsequent deformation.

Additional provenance studies will aid in the understanding of the facies distributions within the subbasins.

It is recommended that supplementary high-resolution seismic surveys be shot across the Petitcodiac Subbasin in order to facilitate a better understanding of the extent and structural discontinuity of clastic sequences.

Several deep wells are needed at strategic locations within both the Petitcodiac and Sackville subbasins in order to gain a more complete assessment of the distribution and thickness of the Horton Group sections there.

REFERENCES

Aydin, A. and Nur, A., 1982. Evolution of pull-apart basins and their scale independence: Tectonics, Volume 1, pp. 91-105.

Ball. F.D., Sullivan, R.M. and Peach, A.R., 1981. Carboniferous drilling project: New Brunswick Department of Natural Resources, Mineral Resources, Report of Investigation, Number 18, 109 p.

Barnett, D.E. and Martel, A.T., 1985. Energy resources. In New Brunswick's mineral industry, 1984. Edited by B.M.W. Carroll: New Brunswick Department of Natural Resources, Mineral Resources Division, Information Circular 85-2, pp. 82-85.

Barnett, D.E., Martel, A.T. and Shaw R., 1985. Energy resources. In New Brunswick's mineral industry, 1984. Edited by B.M.W. Carroll: Mineral Resources Division, Department of Natural Resources, Province of New Brunswick, Information Circular 85-2, pp. 132-135.

Bradley, D.C., 1982. Subsidence in Late Paleozoic basins in the northern Appalachians: Tectonics, Volume 1, pp. 107-123.

Carr, P.A., 1968. Stratigraphy and spore assemblages, Moncton map area, New Brunswick. Geological Survey of Canada, Paper 67-29, 47 p.

Carroll, B.M.W. (Editor), 1984. Energy resources and peat. In New Brunswick's mineral industry, 1983: New Brunswick Department of Natural Resources, Mineral Resources Division, Information Circular 84-1, pp. 97-106.

Carroll, B.M.W. (Editor), 1986. Energy resources. In New Brunswick's mineral industry, 1985: New Brunswick Department of Natural Resources and Energy, Mineral Resources Division, Information Circular 86-1, pp. 100-104.

Carter, D.C. and Pickerill, R.K., 1985a. Algal swamp, marginal and shallow evaporitic lacustrine lithofacies from the Late Devonian-Early Carboniferous Albert Formation, southeastern New Brunswick, Canada: Maritime Sediments and Atlantic Geology, Volume 21, pp. 69-86.

Carter, D.C. and Pickerill, R.K., 1985b. Lithostratigraphy of the Late Devonian - Early Carboniferous Horton Group of the Moncton Subbasin, Southern New Brunswick: Maritime Sediments and Atlantic Geology, Volume 21, pp. 11-24.

Chowdhury, A.H., (in prep.). Sedimentology, diagenesis and organic geochemistry of the Albert Formation, New Brunswick: Geological Survey of Canada Report.

Chowdhury, A.H., Fowler, M.G., Noble, J.P.A., Brooks, P. and Snowdon, L.R., (in press). Petroleum geochemistry of the Albert Formation, Moncton Subbasin, New Brunswick (Abstract): Proceedings of American Association of Petroleum Geologists Annual Meeting, San Antonio, Texas.

Dawson, J.W., 1873. Report of fossil plants of the Lower Carboniferous and Millstone Grit Formations of Canada: Geological Survey of Canada, Separate Report 430, 47 p.

Giles, P.S. and Ruitenberg, A.A., 1976. Stratigraphy, paleogeography, and tectonic setting of the Coldbrook Group in the Caledonia Highlands of southern New Brunswick: Canadian Journal of Earth Science, Volume 14, pp. 1263-1275.

Greiner, H.R., 1962. Facies and sedimentary environments of Albert shale, New Brunswick: Bulletin of the American Association of Petroleum Geologists, Volume 46, Number 2, pp. 219-234.

Greiner, H.R., 1974. The Albert Formation of New Brunswick: A Paleozoic lacustrine model: Geologische Rundschau 63, pp. 1102-1113.

Greiner, H.R., 1977. Crossopterygian fauna from the Albert Formation, New Brunswick, Canada, and its stratigraphic-paleoecologic significance: Journal of Paleontology, Volume 51, pp. 44-56.

Gussow, W.C., 1953. Carboniferous stratigraphy and structural Geology of New Brunswick, Canada: Bulletin of the American Association of Petroleum Geologists, Volume 37, Number 7, pp. 1713-1816.

Hacquebard, P.A., 1972. The Carboniferous of Eastern Canada. In 7th Congress International de Stratigaphie et de Geologie du Carbonifere, Krefeld Comptes Rendus, Bd. 1, pp. 69-90.

Harding, T.P., 1976. Tectonic significance and hydrocarbon consequences of sequential folding synchronous with San Andreas faulting, San Joaquin Valley, California: Bulletin of the American Association of Petroleum Geologists, Volume 60, pp. 356-378.

Henderson, J.A.L., 1940. The development of oil and gas in New Brunswick: The Canadian Mining and Metallurgical Bulletin, Number 336, pp. 159-178.

Howell, D.G., Crouch, J.K., Greene, H.G., McCulloch, D.S., and Vedder, J.G., 1980. Basin development along the late Mesozoic and Cainozoic California margin: A plate tectonic margin of subduction, oblique subduction and transform tectonics. In Sedimentation in oblique-slip mobile zones. Edited by P.F. Ballance and H.G. Reading. International Association of Sedimentologists, Special Publication Number 4, pp. 43-62.

Howie, R.D., 1968. Stony Creek gas and oil field, New Brunswick: American Association of Petroleum Geologists, Memoir 9, pp. 1819-1832.

Howie, R.D., 1979. The Albert Formation, New Brunswick - deltas and oil shale: Geological Survey of Canada Open File Report 671, 18 p.

Hume, G.S., 1932. Oil and gas in eastern Canada: Canada Department of Mines, Geological Survey, Economic Geology Series, Number 9, 183 p.

Kalkreuth, W. and Macauley, G, 1984. Organic petrology of selected oil shale samples from the Lower Carboniferous Albert Formation, New Brunswick, Canada: Bulletin of Canadian Petroleum Geology, Volume 32, Number 1, pp. 38-51.

King, L.H., 1963. Origin of the Albert Mines oil shale (New Brunswick) and its associated albertite: Department of Mines and Technical Surveys, Ottawa, Canada; Mines Branch Research Report R115, 27p.

Leger, A., 1986. Transcurrent faulting history of southern New Brunswick: Unpublished MSc. thesis, University of New Brunswick, Fredericton, New Brunswick, 170 p.

Leger, A. and Williams, P.F., 1986. Transcurrent faulting history of southern New Brunswick: In Current Research, Part b, Geological Survey of Canada, Paper 86-1B, pp. 111-120.

Macauley, G. and Ball, F.D., 1982. Oil shales of the Albert Formation, New Brunswick: New Brunswick Deparment of Natural Resources, Mineral Resouces Division, Open File Report 82-12, 173 p.

Martel, A.T., 1987. Seismic stratigraphy and hydrocarbon potential of the strike-slip Sackville Subbasin, New Brunswick. In Sedimentary basins and basin forming mechanisms. Edited by C. Beaumont and A.J. Tankard: Canadian Society of Petroleum Geologist, Memoir 12, pp. 319-334.

McCutcheon, S.R., 1978. Geology of the Apohaqui - Markhamville area, Map area R-25 (21H/11W, 21H/12E): New Brunswick Department of Natural Resources, Mineral Resources Division, Map Report 78-5, 41 p.

McCutcheon, S.R., 1981. Stratigraphy and paleogeography of the Windsor Group in southern New Brunswick: New Brunswick Department of Natural Resources Geological Surveys Branch, Open File Report 81-31, 210 p.

McCutcheon, S.R. and Robinson, P.T., 1987. Geological constraints on the geresis of the Maritimes Basin, Atlantic Canada. In Sedimentary basins and basin forming mechanisms. Edited by C. Beaumont and A.J. Tankard: Canadian Society of Petroleum Geologists, Memoir 12, pp. 287-297.

McLeod, M.J., 1980. Geology and mineral deposits of the Hillsborough area, map-area V-22 and V-23 (parts of 21 H/15E and 21 H/15W): New Brunswick Department of Natural Resources, Mineral Resources, Map Report 79-6, 35 p.

McLeod, M.J. and Ruitenberg, A.A., 1978. Geology and mineral deposits of the Dorchester area map area W-22, W-23 (21H/15E, 21H/16W): New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Report 78-4, 27 p.

Mount, Van, S. and Suppe, J., 1987. State of stress near the San Andreas Fault: Implications for wrench tectonics: Geology, Volume 15, pp 1143-1146.

Norman, G.W.H., 1932. Stratigraphy of the Stoney Creek Oil and Gas Field, New Brunswick. In Oil and gas in eastern Canada. Edited by G.S. Hume: Canada Department of Mines, Geological Survey, Economic Geology Series, Number 9, pp. 167-173.

Norman, G.W.H., 1941a. Hillsborough: Albert and Westmorland Counties, New Brunswick: Canada Department of Mines and Resources, Geological Survey, Map 647A.

Norman, G.W.H., 1941b. Moncton: Westmorland and Albert Counties, New Brunswick: Canada Department of Mines and Resources, Geological Survey, Map 646A.

Pickerill, R.K. and Carter, D., 1980. Sedimentary facies and depositional history of the Albert Formation: New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 80-2, 132 p.

Pickerill, R.K., Carter, D.C. and St. Peter, C., 1985. The Albert Formation - oil shales, lakes, fans and deltas: Geological Association of Canada, Mineralogical Association of Canada Joint Annual Meeting, Fredericton, New Brunswick, 1985, Excursion 6, 75 p.

Reading, H.G., 1980. Characteristics and recognition of strike-slip fault systems. In Sedimentation in oblique-slip mobile zones. Edited by P.F. Ballance and H.G. Reading. International Association of Sedimentologists, Special Publication Number 4, pp. 43-62.

Ruitenberg, A.A., Giles, P.S., Venugopal, D.V., Buttimer, S.M., McCutcheon, S.R., and Chandra, J., 1979. Geology and mineral deposits, Caledonia Area: New Brunswick Department of Natural Resources, Mineral Resources Branch and Canada Department of Regional Economic Expansion, Memoir 1, 213 p.

Ruitenberg, A.A. and McCutcheon, S.R., 1982. Acadian and Hercynian structural evolution of southern New Brunswick. In Major structural zones and faults of the northern Appalachians. Edited by P. St-Julien and J. Béland: Geological Association of Canada, Special Paper 24, pp.131-148.

Ruitenberg, A.A., Venugopal, D.V. and Giles, P.S., 1973. "Fundy Cataclastic Zone," New Brunswick: Evidence for Post-Acadian Penetrative Deformation: Geological Society of America Bulletin, Volume 84, pp. 3029-3044.

Smith, W.D., 1985. Composition and depositional environment of the Albert Formation oil shales, New Brunswick: Unpublished M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia, 286 p.

Smith, W.D. and Gibling, M.R., 1987. Oil shale composition related to depositional setting: A case study from the Albert Formation, New Brunswick, Canada: Bulletin of Canadian Petroleum Geology, Volume 35, Number 4, pp. 469-487.

St. Peter, C., 1982. Geology of the Albert Formation, New Brunswick, Canada. In Proceedings, 1982 Eastern Oil Shale Symposium. Kentucky Department of Energy and University of Kentucky, Lexington, Kentucky, pp. 39-47.

St. Peter, C., 1987a. Catalogue of well data for boreholes in southern and eastern New Brunswick: New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File Report 87-15, 336 p.

St. Peter, C., 1987b. Geotectonic evolution of the Late Paleozoic Maritimes Basin: Department of Natural Resources and Energy, Minerals and Energy Division, Open File Report 87-14, 129 p.

St. Peter, C., 1988. Assessment of potential sites of recoverable oil shale in New Brunswick: New Brunswick Department of Natural Resources and Energy, Geoscience Report.

Utting, J., 1987. Palynostratigraphic Investigation of the Albert Formation (Lower Carboniferous) of New Brunswick, Canada: Palynology, Volume 11, pp. 73-96.

Varma, C.P., 1969. Lower Carboniferous Miospores from the Albert oil shales (Horton Group) of New Brunswick, Canada: Micropaleontology, Volume 15, pp. 301-324.

Webb, G.W., 1969. Paleozoic wrench faults in Canadian Appalachians. In North Atlantic geology and continental drift, a symposium. Edited by M.Kay: American Association of Petroleum Geologists, Memoir 12, pp.754-786.

Webb, G.W., 1963. Occurrence and exploration significance of strike-slip faults in southern New Brunswick, Canada: Bulletin of the American Association of Petroleum Geologists, Volume 47, Number 11, pp. 1904-1927.

Williams, G.L., Fyffe, L.R., Wardle, R.J., Colman-Sadd, S.P. and Boehner, R.C., (Editors), 1985. Lexicon of Stratigraphy Volume 6, Atlantic Region: Canadian Society of Petroleum Geologists, 572 p.

Wilson, R.A. and Ball, F.D., 1983. Carboniferous compilation (second edition) volume 1: Introduction, hydrocarbons, potash: New Brunswick Department of Natural Resources, Mineral Resources Division, Topical Report 75-19 (revised 1983), 118 p.

Worth, J., 1977. Oil shale and lithofacies, Albert Formation, Hillsborough Subbasin, New Brunswick: Fundy Geoservices Ltd., Report for Canadian Occidental Petroleum Ltd., 79 p.

Wright, W.J., 1922. Geology of the Moncton map area: Canada Department of Mines, Geological Survey, Memoir 129, 69 p.

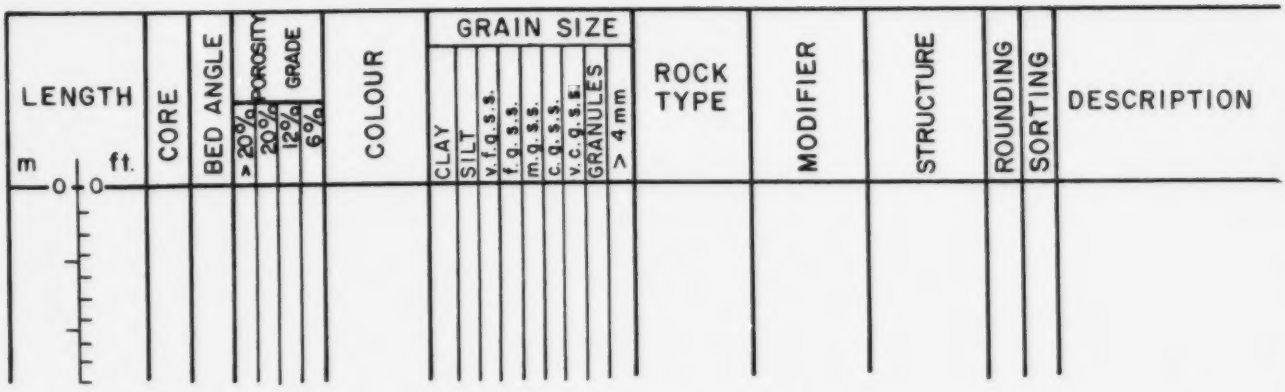
APPENDIX A

LIST OF SYMBOLS AND ABBREVIATIONS USED IN THE LITHOLOGIC LOGS

SYMBOLS, ABBREVIATIONS, and PROCEDURES for NEW BRUNSWICK STANDARD LITHOLOGIC WELL LOG

NATURAL RESOURCES AND ENERGY

LOG FORM



LENGTH

The depth below ground surface can be shown in metres and feet in this column. Any log scale can be chosen and the appropriate numbers inserted. Hatch marks are provided on the right side of the description column so that the log may be horizontally ruled.

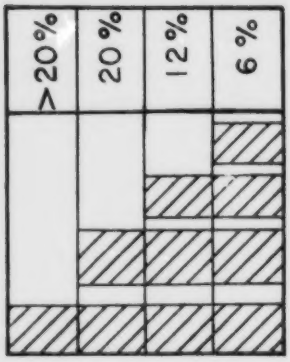
CORE

Shade in the interval in the core column (as shown) for which core was taken.

BED ANGLE

Display the attitude or angle of bedding with respect to core axis. Use column axis to symbolically represent the core axis.

POROSITY GRADE



FOUR DIVISIONS – RIGHT TO LEFT

Division 1, 3% - 6%, poor porosity with low permeability

Division 2, 6% - 12%, fair porosity

Division 3, 12% - 20%, good porosity

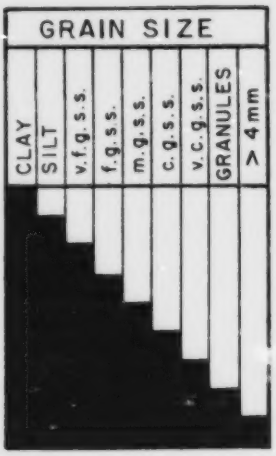
Division 4, over 20%, excellent porosity

porosity not determinable

COLOUR

Colours may be indicated using the appropriate abbreviations, eg. light red to dark brown, lt rd - dk brn

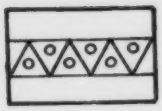
GRAIN SIZE

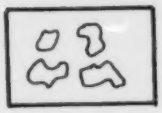


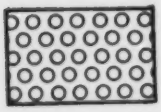
NINE DIVISIONS – LEFT TO RIGHT

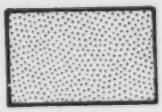
Clay	*less than 0.004 mm*
Silt	*0.004 to 0.063 mm*
v.f.g.s.s.	*0.063 to 0.125 mm*
f.g.s.s.	*0.125 to 0.25 mm*
m.g.s.s.	*0.25 to 0.50 mm*
c.g.s.s.	*0.50 to 1.00 mm*
v.c.g.s.s.	*1.00 to 2.00 mm*
Granules	*2.00 to 4.00 mm*
Pebbles, Cobbles, Boulders	*more than 4.00 mm*

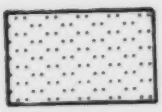
ROCK TYPE

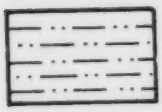

Glacial till, unconsolidated overburden

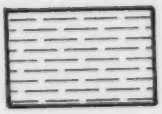

Breccia

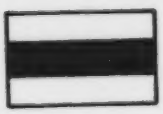

Conglomerate
LT 167

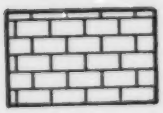

Sandstone
LT 88

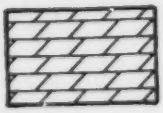

Siltstone
LT 146

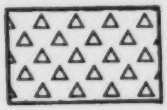

Mudstone

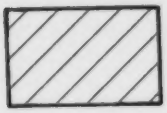

Shale
LT 952

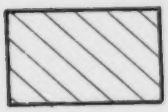

Coal

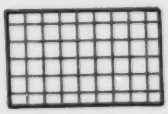

Limestone
LT 243

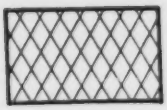

Dolostone
LT 244

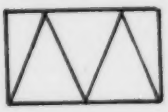

Chert
LT 240

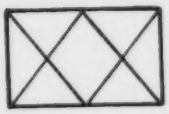

Anhydrite
LT 64


Gypsum
LT 64

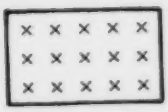

Rock salt
LT 81

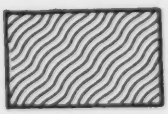

Sylvinite
LT 227


Carnallite

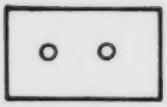

Glauberite

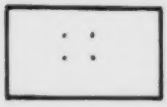
Volcanic flow tuffaceous rock
LT 957

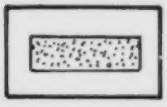

Igneous rock
LT 958

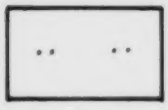

Metamorphic rock
LT 94

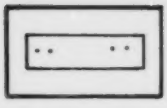
MODIFIER

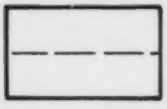

Conglomeratic

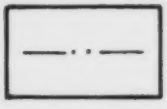

Sandy/arenaceous

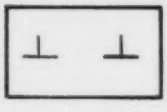

Sandstone stringer

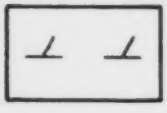

Silty

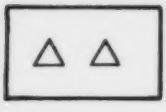

Siltstone stringer

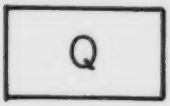

Shaly


Muddy/argillaceous

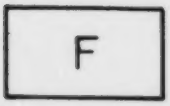

Calcareous


Dolomitic

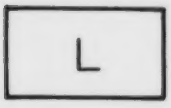

Cherty/siliceous



Quartzose

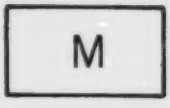


Feldspathic/arkosic

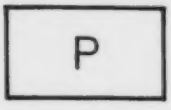


Lithic/polymictic

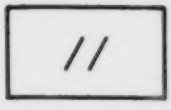
Volcaniclastic tuffaceous

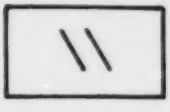


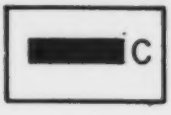
Micaceous



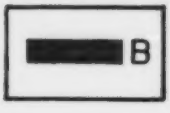
Pyritic


Anhydritic


Gypsiferous

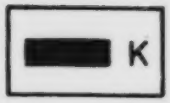


Coaly/carbonaceous



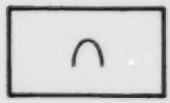
Bituminous

MODIFIER

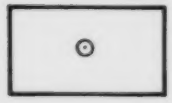


Kerogenous

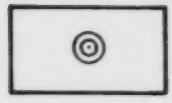
Phosphatic



Bioclastic Intraclastic

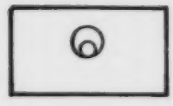


Oolites



Pisolites

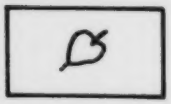
Pellets/lumps
fecal particles



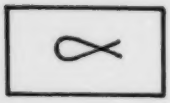
Oncolites/algal balls

Algal/algal laminated

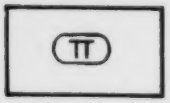
Fossiliferous



Plant remains

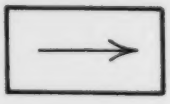


Fish remains

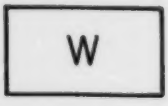


Fish scales

Recrystallized

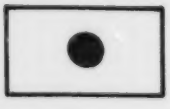


Leached



Weathered

Poor oil stain



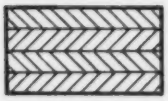
Good oil stain

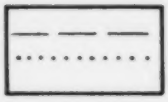
Dead oil stain

STRUCTURE

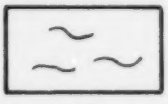
Planar cross-bedding

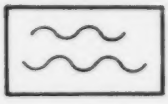
Trough cross-bedding


Herringbone cross-bedding


Graded bedding

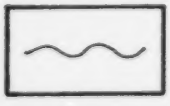
Lenticular beds


Flaser bedding


Nodular beds

Parallel laminations

Varves

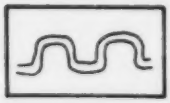

Wave ripples/wavy laminations

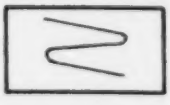
Current ripples or laminations

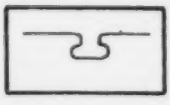
Climbing ripples or laminations

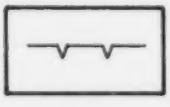
Planar cross-laminations

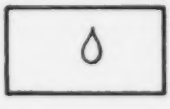
Trough cross-laminations


Convolute beds/ laminations


Slumped beds/ laminations

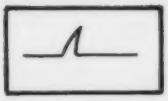

Load cast(s)

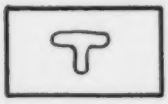

Mud cracks

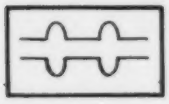

Rain prints

Pull-apart

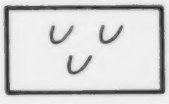
STRUCTURE

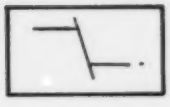

Flame structures

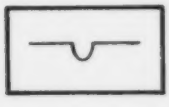

Injection structure

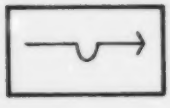

Boudinage/ball and pillow structures

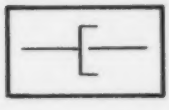
Sandstone dyke

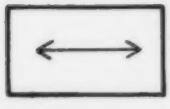

Dish structures

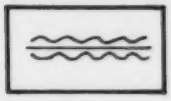

Synsedimentary faults

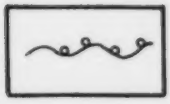

Scour mark(s)

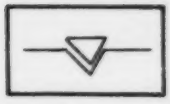

Flute cast(s)


Groove cast(s)

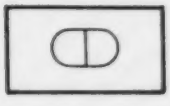

Striations

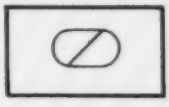

Parting lineation

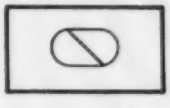

Erosion surface with pebble base

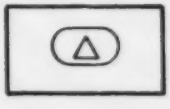

Rip-up clasts

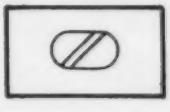
Nodules, indeterminate composition

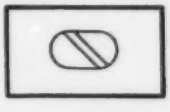

Limestone nodule(s)


Dolomite nodule(s)

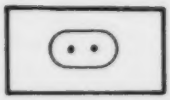

Siderite nodule(s)

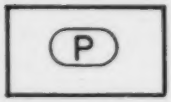

Chert nodule(s)


Anhydrite nodule(s)

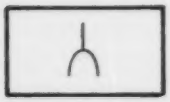

Gypsum nodule(s)

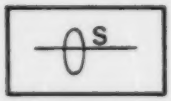
STRUCTURE


Phosphate nodule(s)

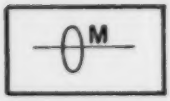


Pyrite nodule(s)

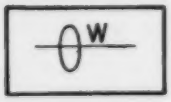

Root tube(s)



Slightly burrowed



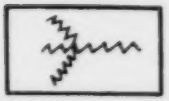
Moderately burrowed

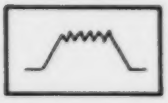


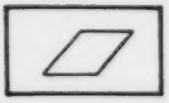
Well burrowed

Churned/bioturbated

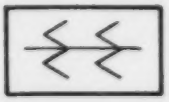
Breccia, solution collapse

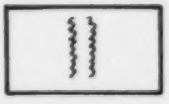

Dissolution compaction


Stylolite(s)


Salt hoppers or casts

Breccia, tectonic


Fractures, tectonic


Slickensides

ROUNDING

A	*Angular*	R	*Rounded*
a	*Subangular*	r	*Subrounded*

SORTING

W	*Well*	*1 or 2 size grades*
M	*Medium*	*3 or 4 size grades*
P	*Poor*	*5 or more size grades*

DESCRIPTION

Additional comments that cannot be accommodated in the other columns of the log may be put here using the abbreviations provided.

STANDARD ABBREVIATIONS FOR LITHOLOGIC DESCRIPTIONS

WORD	ABBREVIATION
about	abt
above	abv
absent	abs
abundant	abnt
acicular	acic
after	aft
agglomerate	aglm
aggregate	agg
albertite	alb
algae, algal	alg
allochem	allo
altered	alt
alternating	altg
amber	amb
amorphous	amor
amount	amt
and	&
angular	ang
anhedral	ahd
anhydrite(-ic)	anhy
anthracite	anthr
aphanitic	aph
apparent	apr
appears	ap
approximate	apprx
aragonite	arag
arenite(-aceous)	aren
argillaceous	arg
arkose(-ic)	ark
as above	a.a.
asphalt(-ic)	asph
assemblage	assem
associated	assoc
authigenic	authg
average	av
band(-ed)	bnd
barite(-ic)	bar
basalt(-ic)	bas
basement	bm
become(-ing)	bcm
bed(-ded)	bd
bedding	bdg
bentonite(-ic)	bent
between	btw
bitumen(-inous)	bit
bioclastic	biocl
bioherm(-al)	bioh
biomicrite	biomi
biosparite	biosp
biostrom(-al)	biost
biotite	biot
bioturbated	bioturb
bird's-eye	bdeye
black(-ish)	blk, blksh
blade(-ed)	blde
blocky	blky
blue(-ish)	bl, blsh
bored(-ing)	bor
bottom	btm
botryoid(-al)	bot
boudinage	boud
boulder	bld
boundstone	bdst
brachiopod	brach
brackish	brak
branching	brhg
break	brk
breccia(-ted)	brec
bright	brt
brittle	brit
brown	brn
bryozoa	bry
bubble	bubl
buff	bu
bulbous	bulb
burrow(-ed)	bur
calcarenite	clcar
calcilutite	clclt
calcirudite	clcrd
calcisiltite	clslt
calcisphere	clcsp
calcite(-ic)	calc, caltc
calcareous	calca
caliche	cche
carbonaceous	carb
carbonate	crbnt
carbonized	cb
cavern(-ous)	cav
caving	cvg
cement(-ed,-ing)	cmt
centimetre	cm
centre(-d)	cntr
cephalopod	ceph
chalcedony(-ic)	chal
chalk(-y)	chk, chky
charophyte	char
chert(-y)	cht
chitin(-ous)	chit
chitinozoan	chtz
chlorite(-ic)	chlor

WORD	ABBREVIATION
chocolate	choc
circulate(-ion)	circ
clast(-ic)	clas
clay(-ey)	cl
claystone	clst
clean	cln
clear	clr
cleavage	clvg
cluster	clus
coal	co
coarse	crs
coarse-grained	cg
coated(-ing)	cotd, cotg,
coated grains	cotd gn
cobble	cbl
colonial	coln
colour(-ed)	col
common	com
compact	cpct
compare	cf
composition	comp
concentric	cncn
conchoidal	conch
concretion(-ary)	conc
conglomerate(-ic)	cgl
conodont	cono
considerable	cons
consolidated	consol
conspicuous	conspic
contact	ctc
contamination(-ed)	contam
content	cont
continuous	ctous
contorted	cntrt
coquina(-oid)	coq,coqid
coral, coralline	cor, corln
core	c, ¢
covered	cov
cream	crm
crenulated	cren
crinkled	crnk
crinoid(-al)	crin, crinal
cross	x
cross-bed(-ded)	x-bd
cross-lamina(-ted, -tions)	x-lam
cross-stratified	x-strat
crumpled	crpld
crush(-ed)	cr
cryptocrystalline	crpxln
crystal(-line)	xl, xln
cube, cubic	cub
cuttings	ctgs
dark(-er)	dk, dkr
dead	dd
debris	deb
decrease(-ing)	decr
dendrite(-ic)	dend
dense	dns
description	descr
desiccation	dess
detritus(-us)	detr
devitrified	devit
diabase	db
diagenesis(-etic)	diagn
diameter	dia
disaggregate(-d)	disagg
discontinuous	disc
disseminated	dissem
dolomite(-ic)	dol
dolostone	dolst
dominant(-ly)	dom
drilling	drlg
drill-stem test	dst
drusy	dru
dusky	dsky
earthy	ea
east	E
elevation	elev
elongate	elong
embedded	embd
equant	eqnt
equivalent	equiv
euhedral	euhd
euxinic	eux
evaporite(-ic)	evap
excellent	ex
exposed	exp
extraclast(-ic)	exclas
extremely	extr
extrusive (rock)	exv
facet(-ed)	fac
faint	fnt
fair	fr
fault(-ed)	flt
fauna	fau
feet	ft
feldspar(-athic)	fspr
felsic	fel
ferromagnesian	fe-mag

WORD	ABBREVIATION
ferruginous	ferr
fibrous	fibr
fill(-ed)	fil
fine(-ly)	f, fnly
fine-grained	fg
fissile	fis
flaggy	flg
flake(-s), flaky	flk(s), flky
flat	fl
flesh	fls
floating	fltg
flora	flo
fluorescence(-ent)	fluor
foliated	fol
foot	ft
formation	fm
fossil(-iferous)	foss
fracture(-d)	frac
fragment(-al)	frag
framework	frmwk
frequent	freq
fresh	frs
friable	fri
fringe(-ing)	frg
frosted	fros
frosted quartz grains	f.q.g.
fucoid(-al)	fuc
gabbro	gab
gastropod	gast
gas	g
generally	gen
geopetal	gept
gilsonite	gil
glass(-y)	glas
glauconite	glauc
gloss(-y)	glos
gneiss(-ic)	gns
good	gd
grade(-ed)	grd
grading	grad
grain(-s, -ed)	gr
grainstone	grst
granite	grt
granite wash	g.w.
granitoid	grtoid
granule(-ar)	gran
grapestone	grapst
gravel	grv
greasy	gsy
green(-ish)	grn, grnsh
grey(-ish)	gry, grysh
greywacke	gwke
grit(-ty)	gt
gypcrete	gypcte
gypsum(-iferous)	gyp
hackly	hkl
halite(-iferous)	hal
hard	hd
heavy	hvy
hematite(-ic)	hem
heterogeneous	hetr
hexagonal	hex
high(-ly)	hi
homogeneous	hom
horizontal	hor
hornblende	hornbd
hydrocarbon	hydrc
igneous (rock)	ig
imbedded	imbd
impression	imp
inch	in
inclined	incd
inclusion(-ded)	incl
increasing	incr
indistinct	indst
indurated	ind
in part	i.p.
insoluble	insl
interbedded	intbd
intercalated	intercal
intercrystalline	intxln
interfragmental	intfrag
intergranular	intgran
intergrown	intgn
interlaminated	intlam
interparticle	intpar
interpretation	intpt
intersticies(-itial)	intst
interval(-s)	intvl(s)
intraclast(-ic)	intclas
intraformational	intfm
intraparticle	intrapar
intrusive (rock)	intr
invertebrate	invtb
ironstone	fe-st
irregular(-ly)	irr
irridescent	irrid
isopachous	iso

WORD	ABBREVIATION
jasper	jasp
joint(-ed,-ing)	jt
kaolin(-itic)	kao
kerogen(-ous)	ker
lacustrine	lac
lamina(-tions,-ted)	lam
large	lge
laterite(-ic)	lat
lavender	lav
layer	lyr
leached	lchd
lenticular	lent
light	lt
lignite(-ic)	lig
limestone	ls
limonite(-ic)	lim
limy	lmy
litharenite	litaren
lithic	lit
lithic arkosic wacke	litarkwke
lithographic	lithgr
lithology(-ic)	lith
lithwacke	litwke
little	ltl
littoral	litt
local(-ly)	loc
long	lg
loose	lse
lower	l
lumpy	lmpy
lustre	lstr
lutite	lut
macrofossil	macrofos
mafic	mf
magnetite, magnetic	mag
manganese(-iferous)	mn
marble	mbl
marl(-y)	mrl
marlstone	mrlst
marine	marn
maroon	mar
massive	mass
material	mat
matrix	mtrx
maximum	max
medium	med
medium-grained	mg
member	mbr
meniscus	men
metamorphic (rock)	meta
metamorphosed	metaph
metasomatic	msm
metre	m
mica(-ceous)	mic
micrite(-ic)	micr
micro	micro
microcrystalline	microxln
microfossil(-iferous)	microfos
micrograined	micgr
micro-oolite	microol
micropore(-osity)	micropor
microstylolite	microstyl
middle	mid
milky	mky
millimetre	mm
mineral(-ized)	min
minor	mnr
minute	minu
moderate	mod
mold(-ic)	mol
mollusc	moll
mosaic	mos
mottled	mott
mud(-dy)	md, mdy
mudstone	mdst
muscovite	musc
nacreous	nac
no, none, non	no
nodules(-ar)	nod
north	N
no sample	n.s.
no show	n/s
novaculite	novac
no visible porosity	n.v.p.
numerous	num
occasional	occ
ochre	och
odour	od
oil	o
oil source rock	osr
olive	olv
olivine	olvn
oocast	oocst
ooid(-al)	oo
oolicast(-ic)	ooc
oolite	ool
oomold(-ic)	oomol

WORD	ABBREVIATION
oncolite(-oidal)	onc
opaque	op
orange(-ish)	or, orsh
organic	org
orthoclase	orth
orthoquartzite	o-qtz
ostracod	ostr
overgrowth	ovgth
oxidized	ox
packstone	pkst
paper(-y)	pap
parallel	pll
part(-ly)	pt
particle	par
parting	ptg
parts per million	ppm
patch(-y)	pch
pearly	prly
pebble(-ly)	pbl
pelecypod	pelec
pellet(-al)	pel
pelletoid(-al)	peld
permeability(-able)	k, perm
pendular(-ous)	pend
petroleum(-iferous)	pet
phenocrysts	phen
phlogopite	phlog
phosphate(-ic)	phos
phyllite(-ic)	phyl
phreatic	phr
pink(-ish)	pk, pksh
pin-point porosity	p.p.
pisolite(-ic)	pisol
pitted	pit
plagioclase	plag
plant	plt
plastic	plas
platy	plty
plutonic	plut
polish(-ed)	pol
polygonal	poly
poor(-ly)	p
porcelaneous	porcel
porosity, porous	ø, por
porphyry(-itic)	prphy
possible(-y)	poss
potassium feldspar	kspr
predominant(-ly)	pred
preserved	pres
pressure deformation	p-d
primary	prim
prism(-atic)	pris
probable(-y)	prob
production	prod
prominent	prom
pseudo-	ps
pseudo-oolite(-ic)	psool
pumice stone	pst
purple(-ish)	purp, purpsh
pyrite(-ize,-ic)	pyr
pyrobitumen	pybit
pyroclastic	pyrcl
pyroxene	pyrox
quartz(-ose)	qtz
quartzarenite	qtzaren
quartzite(-ic)	qtzt
quartzwacke	qtzwke
radial(-ating)	rad
radiaxial	radax
range	rng
rare	r
recemented	recem
recovery(-ed)	rec
recrystallized	rexlzd
red(-dish)	rd, rdsh
reduction	redu
reef(-oid)	rf
remains	rem
replaced(-ment)	rep
residue(-al)	res
resinous	rsns
rhomb(-ic)	rhb
ripple	rpl
rock(-s)	rk, rks
round(-ed)	rnd, rndd
rubble(-y)	rbl
rudist	rud
rugose (rugosa)	rug
saccharoidal	sacc
salt(-y)	sa
salt and pepper	s & p
salt cast(-ic)	sa-c
salt water	s.w.
same as above	a.a.
sample	spl
sand(-y)	sd, sdy
sandstone	ss
saturation(-ed)	sat

WORD	ABBREVIATION
scales	sc
scarce	scs
scattered	scat
schist(-ose)	sch
secondary	sec
sediment(-ary)	sed
selenite	sel
septate	sept
shadow	shad
shale(-y)	sh
shell	shl
shelter porosity	shlt por
show	shw
siderite(-ic)	sid
sidewall core	s.w.c.
silica(-eous)	sil
silky	slky
silt	slt
silty	slty
siltstone	sltst
similar	sim
size	sz
skeletal	skel
slabby	slb
slate	sl
slickenside(-d)	slick
slight(-ly)	sli, slily
small	sml
smooth	sm
soft	sft
solitary	sty
solution, soluble	sol
somewhat	smwt
sorted(-ing)	srt, srtg
south	S
spar(-ry)	spr
sparse(-ly)	sps, spsly
speck(-led)	spk, spkld
sphalerite	sphal
spherule(-itic)	spher
spicule(-ar)	spic
splintery	splin
spore	spo
spots	spts
spotted(-y)	sptd, spty
stain(-ed, -ing)	stn
stalactitic	stal
strata(-ified)	strat
streak	strk
streaming	stmg
striae(-ted)	stri

WORD	ABBREVIATION
stringer(-s)	strgr, strgrs
stromatolite(-ic)	stromlt
structure	str
stylolite(-ic)	styl
sub (as a prefix)	sb
subangular	sbang
subarkose	sbark
sublitharenite	sblitaren
sublithic	sblit
sublithwacke	sblitwke
subrounded	sbrndd
sucrosic	suc
sugary	sug
sulphur(-ous)	su
superficial oolites	spfool
surface	surf
syntaxial	syn
tabular(-ate)	tab
tan	tn
tension	ten
terrigenous	ter
texture(-d)	tex
thick	thk
thin	thn
thin-bedded	t.b.
thin section	t.s.
throughout	thru
tight	ti
to	/ or -
top	tp
tough	tgh
trace	tr
translucent	trnsl
transparent	trnsp
tripoli(-c)	trip
tube(-ular)	tub
tuff(-aceous)	tf
type(-ical)	typ
unconformity	unconf
unconsolidated	uncons
underclay	uc
underlying	undly
unidentifiable	unident
uniform	uni
upper	u
vadose	vad
variation	var
varicoloured	varic

WORD	ABBREVIATION
variegated	vgt
varved	vrvd
vein(-ing, -ed)	vn
veinlet	vnlet
vermillion	verm
vertebrate	vrtb
vertical	vert
very	v
very poor sample	v.p.s.
vesicular	ves
violet	vi
visible	vis
vitreous(-ified)	vit
volatile	volat
volcanic (rock)	volc
vug(-gy)	vug
wacke	wke
wackestone	wkst
washed residue	w.r.
water	wtr
wavy	wvy
waxy	wxy
weak	wk
weathered	wthd
well	wl
west	W
white	wh
with	w/
without	w/o
wood	wd
yellow(-ish)	yel, yelsh
zeolite	zeo
zircon	zr
zone	zn

ABBREVIATION	WORD
/ or -	to
&	and
a.a.	as above
abnt	abundant
abs	absent
abt	about
abv	above
acic	acicular
aft	after
agg	aggregate
aglm	agglomerate
alb	albertite
alg	algae, algal
allo	allochem
alt	altered
altg	alternating
amb	amber
amor	amorphous
amt	amount
ahd	anhedral
ang	angular
anhy	anhydrite(-ic)
ap	appears
aph	aphanitic
apprx	approximate
apr	apparent
anthr	anthracite
arag	aragonite
aren	arenite(-aceous)
arg	argillaceous
ark	arkose(-ic)
asph	asphalt(-ic)
assem	assemblage
assoc	associated
authg	authigenic
av	average
bar	barite(-ic)
bas	basalt(-ic)
bcm	become(-ing)
bd	bed(-ded)
bdeye	bird's-eyec)
bdg	bedding
bdst	boundstone
bent	bentonite(-ic)
biocl	bioclastic
bioh	bioherm(-al)
biomi	biomicrite
biosp	biosparite
biost	biostrom(-al)
biot	biotite

ABBREVIATION	WORD
bioturb	bioturbated
bit	bitumen(-inous)
bl, blsh	blue(-ish)
bld	boulder
blde	blade(-ed)
blk, blksh	black(-ish)
blky	blocky
bm	basement
bnd	band(-ed)
bor	bored(-ing)
bot	botryoid(-al)
boud	boudinage
brach	brachiopod
brak	brakish
brec	breccia(-ted)
brhg	branching
brit	brittle
brk	break
brn	brown
brt	bright
bry	bryozoa
btm	bottom
btw	between
bu	buff
bubl	bubble
bulb	bulbous
bur	burrow(-ed)
c, ¢	core
calc, caltc	calcite(-ic)
calca	calcareous
carb	carbonaceous
cav	cavern(-ous)
cb	carbonized
cbl	cobble
cche	caliche
ceph	cephalopod
cf	compare
cg	coarse-grained
cgl	conglomerate(-ic)
chal	chalcedony(-ic)
char	charophyte
chit	chitin(-ous)
chk, chky	chalk(-y)
chlor	chlorite(-ic)
choc	chocolate
cht	chert(-y)
chtz	chitinozoan
circ	circulate(-ion)
cl	clay(-ey)
clas	clast(-ic)

ABBREVIATION	WORD
clcar	calcarenite
clclt	calcilutite
clcrd	calcirudite
clcsp	calcisphere
cln	clean
clr	clear
clslt	calcisiltite
clst	claystone
clus	cluster
clvg	cleavage
cm	centimetre
cmt	cement(-ed, -ing)
cncn	concentric
cntr	centre(-d)
cntrt	contorted
co	coal
col	colour(-ed)
coln	colonial
com	common
comp	composition
conc	concretion(-ary)
conch	conchoidal
cono	conodont
cons	considerable
consol	consolidated
conspic	conspicuous
cont	content
contam	contamination(-ed)
coq, coqid	coquina(-oid)
cor, corln	coral, coralline
cotd, cotg	coated(-ing)
cotd gn	coated grains
cov	covered
cpct	compact
crbnt	carbonate
cr	crush(-ed)
cren	crenulated
crin, crinal	crinoid(-al)
crm	cream
crnk	crinkled
crpld	crumpled
crpxln	cryptocrystalline
crs	coarse
ctc	contact
ctgs	cuttings
ctous	continuous
cub	cube, cubic
cvg	caving
db	diabase
dd	dead

ABBREVIATION	WORD
deb	debris
decr	decrease(-ing)
dend	dendrite(-ic)
descr	description
dess	desiccation
detr	detritus(-al)
devit	devitrified
dia	diameter
diagn	diagenesis(-etic)
disagg	disaggregate(-d)
disc	discontinuous
dissem	disseminated
dist	distilate
dk, dkr	dark(-er)
dns	dense
dol	dolomite(-ic)
dolst	dolostone
dom	dominant(-ly)
drlg	drilling
dru	drusy
dsky	dusky
dst	drill-stem test
E	east
ea	earthy
elev	elevation
elong	elongate
embd	embedded
eqnt	equant
equiv	equivalent
euhd	euhedral
eux	euxinic
evap	evaporite(-ic)
ex	excellent
exclas	extraclast(-ic)
exp	exposed
extr	extremely
exv	extrusive (rock)
f, fnly	fine(-ly)
fac	facet(-ed)
fau	fauna
fel	felsic
fe-mag	ferromagnesian
ferr	ferruginous
fe-st	ironstone
fibr	fibrous
fil	fill(-ed)
fg	fine-grained
fis	fissile
fl	flat
flg	flaggy
flk(s), flky	flake(-s), flaky
flo	flora
fls	flesh
flt	fault(-ed)
fltg	floating
fluor	fluorescence(-ent)
fm	formation
fnt	faint
fol	foliated
foss	fossil(-iferous)
fr	fair
frac	fracture(-d)
frag	fragment(-al)
freq	frequent
frg	fringe(-ing)
fri	friable
frmwk	framework
fros	frosted
frs	fresh
f.q.g.	frosted quartz grains
fspr	feldspar(-athic)
ft	foot, feet
fuc	fucoid(-al)
g	gas
gab	gabbro
gast	gastropod
gd	good
gen	generally
gept	geopetal
gil	gilsonite
glas	glass(-y)
glauc	glauconite
glos	gloss(-y)
gns	gneiss(-ic)
gr	grain(-s, -ed)
grad	grading
gran	granule(-ar)
grapst	grapestone
grd	grade(-ed)
grn, grnsh	green(-ish)
grst	grainstone
grt	granite
grtoid	granitoid
grv	gravel
gry, grysh	grey(-ish)
gsy	greasy
gt	grit(-ty)
g.w.	granite wash
gwke	greywacke

ABBREVIATION	WORD
gyp	gypsum(-iferous)
gypcte	gypcrete
hal	halite(-iferous)
hd	hard
hem	hematite(-ic)
hetr	heterogeneous
hex	hexagonal
hi	high(-ly)
hkl	hackly
hom	homogeneous
hor	horizontal
hornbd	hornblende
hvy	heavy
hydrc	hydrocarbon
ig	igneous (rock)
imbd	imbedded
imp	impression
in	inch
incd	inclined
incl	inclusion(-ded)
incr	increasing
ind	indurated
indst	indistinct
i.p.	in part
insl	insoluble
intbd	interbedded
intclas	interclast(-ic)
intercal	intercalated
intfm	intraformational
intfrag	interfragmental
intgran	intergranular
intgn	intergrown
intlam	interlaminated
intpar	interparticle
intpt	interpretation
intr	intrusive (rock)
intrapar	intraparticle
intst	intersticies(-itial)
intvl(s)	interval(-s)
intxln	intercrystalline
invtb	invertebrate
irr	irregular(-ly)
irrid	irridescent
iso	isopachous
jasp	jasper
jt	joint(-ed, -ing)
k	permeability(-able)

ABBREVIATION	WORD
kao	kaolin(-itic)
ker	kerogen(-ous)
kspr	potassium feldspar
l	lower
lac	lacustrine
lam	lamina(-tions, -ted)
lat	laterite(-ic)
lav	lavender
lchd	leached
lent	lenticular
lg	long
lge	large
lig	lignite(-ic)
lim	limonite(-ic)
lit	lithic
litaren	litharenite
litarkwke	lithic arkosic wacke
lith	lithology(-ic)
lithgr	lithographic
litt	littoral
litwke	lithwacke
lmpy	lumpy
lmy	limy
loc	local(-ly)
ls	limestone
lse	loose
lstr	lustre
lt	light
ltl	little
lut	lutite
lyr	layer
m	metre
macrofos	macrofossil
mag	magnet(-ite, -ic)
mar	maroon
marn	marine
mass	massive
mat	material
max	maximum
mbl	marble
mbr	member
md, mdy	mud(-dy)
mdst	mudstone
med	medium
men	meniscus
meta	metamorphic (rock)
metaph	metamorphosed
mf	mafic
mg	medium-grained

ABBREVIATION	WORD
mic	mica(-ceous)
micgr	micrograined
micr	micrite(-ic)
micro	micro
microfos	microfossil(-iferous)
microol	micro-oolite
micropor	micropore(-osity)
microstyl	microstylolite
microxln	microcrystalline
mid	middle
min	mineral(-ized)
minu	minute
mky	milky
mm	millimetre
mn	manganese(-iferous)
mnr	minor
mod	moderate
mol	mold(-ic)
moll	mollusc
mos	mosaic
mott	mottled
mrl	marl(-y)
mrlst	marlstone
msm	metasomatic
mtrx	matrix
musc	muscovite
N	north
nac	nacreous
no	no, none, non
nod	nodules(-ar)
n.s.	no sample
n/s	no show
novac	novaculite
n.v.p.	no visible porosity
num	numerous
o	oil
occ	occasional
och	ochre
od	odour
olv	olive
olvn	olivine
onc	oncolite(-oidal)
oo	ooid(-al)
ooc	oolicast(-ic)
oocst	oocast
ool	oolite
oomol	oomold(-ic)
op	opaque
o-qtz	orthoquartzite

ABBREVIATION	WORD
or, orsh	orange(-ish)
org	organic
orth	orthoclase
osr	oil source rock
ostr	ostracod
ovgth	overgrowth
ox	oxidized
p	poor(-ly)
pap	paper(-y)
par	particle
pbl	pebble(-y)
pch	patch(-y)
p-d	pressure deformation
pel	pellet(-al)
peld	pelletoid(-al)
pelec	pelecypod
pend	pendular(-ous)
perm	permeability(-able)
pet	petroleum(-iferous)
phen	phenocrysts
phlog	phlogopite
phos	phosphate(-ic)
phr	phreatic
phyl	phyllite(-ic)
pisol	pisolite(-ic)
pit	pitted
pk, pksh	pink(-ish)
pkst	packstone
plag	plagioclase
plas	plastic
pll	parallel
plt	plant
plty	platy
plut	plutonic
pol	polish(-ed)
poly	polygonal
por, ø	porosity(-ous)
porcel	porcelaneous
poss	possible(-y)
p.p.	pin-point porosity
ppm	parts per million
pred	predominant(-ly)
pres	preserved
prim	primary
pris	prism(-atic)
prob	probable(-y)
prod	production
prom	prominent
prly	pearly
prphy	porphyry(-itic)

ABBREVIATION	WORD
ps	pseudo
psool	pseudo-oolite(-ic)
pst	pumice stone
pt	part(-ly)
ptg	parting
purp, purpsh	purple(-ish)
pybit	pyrobitumen
pyr	pyrite(-ize, -ic)
pyrocl	pyroclastic
pyrox	pyroxene
qtz	quartz(-ose)
qtzaren	quartzarenite
qtzt	quartzite(-ic)
qtzwke	quartzwacke
r	rare
rad	radial(-iating)
radax	radiaxial
rbl	rubble(-y)
rd, rdsh	red(-dish)
rec	recovery(-ed)
recem	recemented
redu	reduction
rem	remains
rep	replaced(-ment)
res	residue(-al)
rexlzd	recrystallized
rf	reef(-oid)
rhb	rhomb(-ic)
rk, rks	rock(-s)
rnd, rndd	round(-ed)
rng	range
rpl	ripple
rsns	resinous
rud	rudist
rug	rugose (rugosa)
S	south
sa	salt(-y)
sacc	saccharoidal
sat	saturation(-ed)
sb	sub (as a prefix)
sbang	subangular
sbark	subarkose
sblit	sublithic
sblitaren	sublitharenite
sblitwke	sublithwacke
sbrndd	subrounded
sc	scales
scat	scattered

ABBREVIATION	WORD
sch	schist(-ose)
scs	scarce
sd, sdy	sand(-y)
sec	secondary
sed	sediment(-ary)
sel	selenite
sept	septate
sft	soft
sh	shale(-y)
shad	shadow
shl	shell
shlt por	shelter porosity
shw	show
sid	siderite(-ic)
sil	silica(-eous)
sim	similar
skel	skeletal
sl	slate
slb	slabby
slick	slickenside(-d)
sli, slily	slight(-ly)
slky	silky
slt	silt
sltst	siltstone
slty	silty
sm	smooth
sml	small
smwt	somewhat
sol	solution, soluble
s & p	salt and pepper
spfool	superficial oolites
sphal	sphalerite
spher	spherule(-itic)
spic	spicule(-ar)
spk, spkld	speck(-led)
spl	sample
splin	splintery
spo	spore
spr	spar(-ry)
sps, spsly	sparse(-ly)
sptd, spty	spotted(-y)
spts	spots
srt, srtg	sorted(-ing)
ss	sandstone
stal	stalactitic
stmg	streaming
stn	stain(-ed, -ing)
str	structure
strat	strata(-ified)
strgr, strgrs	stringer(-s)
stri	striae(-ted)

ABBREVIATION	WORD
strk	streak
stromlt	stromatolite(-ic)
sty	solitary
styl	stylolite(-ic)
su	sulphur(-ous)
suc	sucrosic
sug	sugary
surf	surface
s.w.	salt water
s.w.c.	side wall core
syn	syntaxial
sz	size
tab	tabular(-ate)
t.b.	thin-bedded
ten	tension
ter	terrigenous
tex	texture(-d)
tf	tuff(-aceous)
tgh	tough
thk	thick
thn	thin
thru	throughout
ti	tight
tn	tan
tp	top
tr	trace
trip	tripoli(-c)
trnsl	translucent
trnsp	transparent
t.s.	thin section
tub	tube(-ular)
typ	type(-ical)
u	upper
uc	underclay
unconf	unconformity
uncons	unconsolidated
undly	underlying
uni	uniform
unident	unidentifiable
v	very
vad	vadose
var	variation
varic	varicoloured
verm	vermillion
vert	vertical
ves	vesicular
vgt	variegated
vi	violet
vis	visible
vit	vitreous(-ified)
vn	vein(-ing, -ed)
vnlet	veinlet
volat	volatile
volc	volcanic (rock)
v.p.s.	very poor sample
vrtb	vertebrate
vrvd	varved
vug	vug(-gy)
W	west
w/	with
w/o	without
wd	wood
wh	white
wk	weak
wke	wacke
wkst	wackestone
wl	well
w.r.	washed residue
wthd	weathered
wtr	water
wvy	wavy
wxy	waxy
x	cross
x-bd	cross-bed(-ded)
xl, xln	crystal(-line)
x-lam	cross-lamina(-tions, -ted)
x-strat	cross-stratified
yel, yelsh	yellow(-ish)
zeo	zeolite
zn	zone
zr	zircon

APPENDIX B

THREE-DIMENSIONAL COMPUTER MODELS

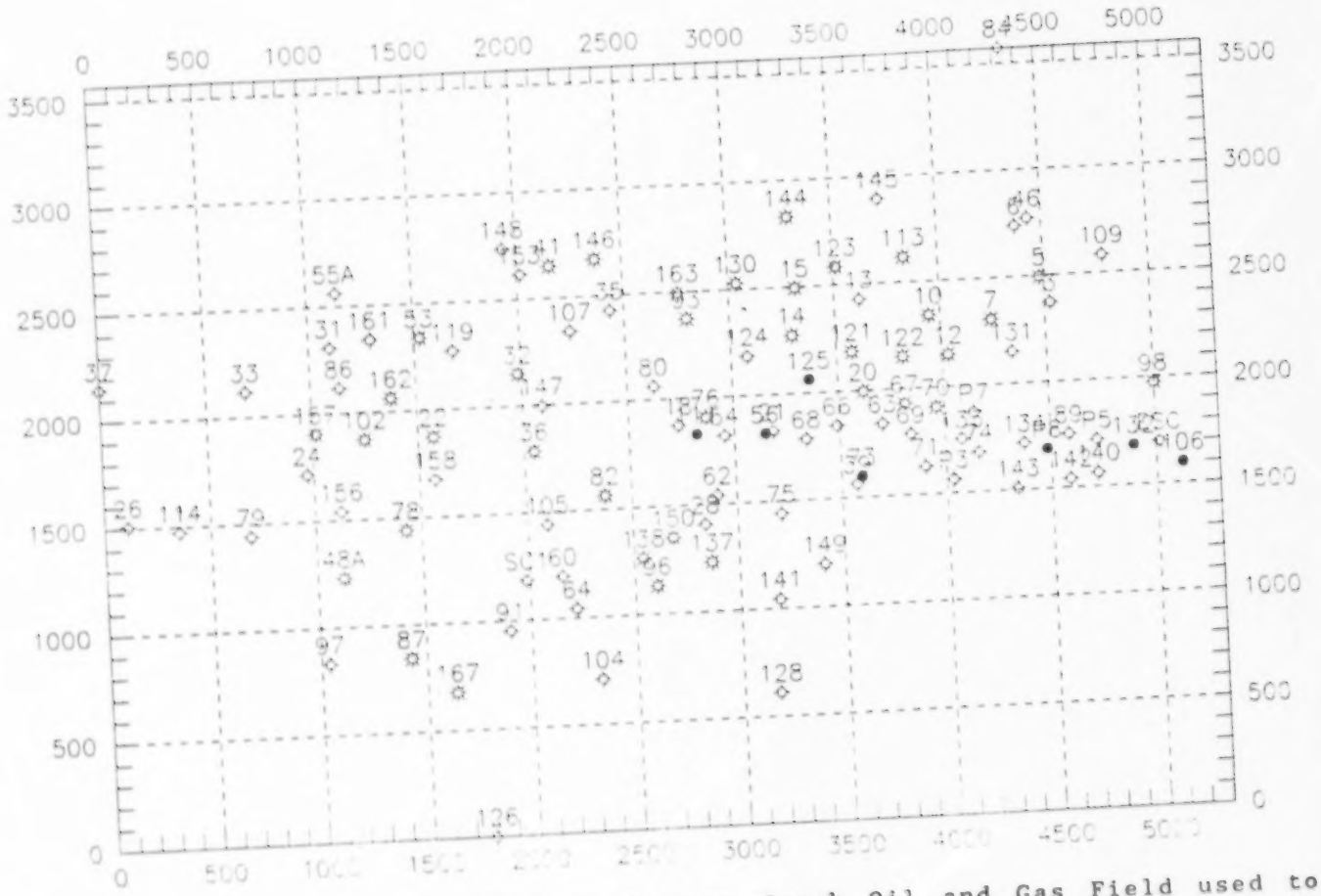


Figure 20: Location of wells at Stoney Creek Oil and Gas Field used to generate the three-dimensional models (see Figures 21-35). A solid circle indicates a presently producing oil well; an open circle surrounded by eight radiating ticks, a presently producing gas well; and an open circle surrounded by four radiating ticks, a nonproducing well. The coordinate axes are in metres.

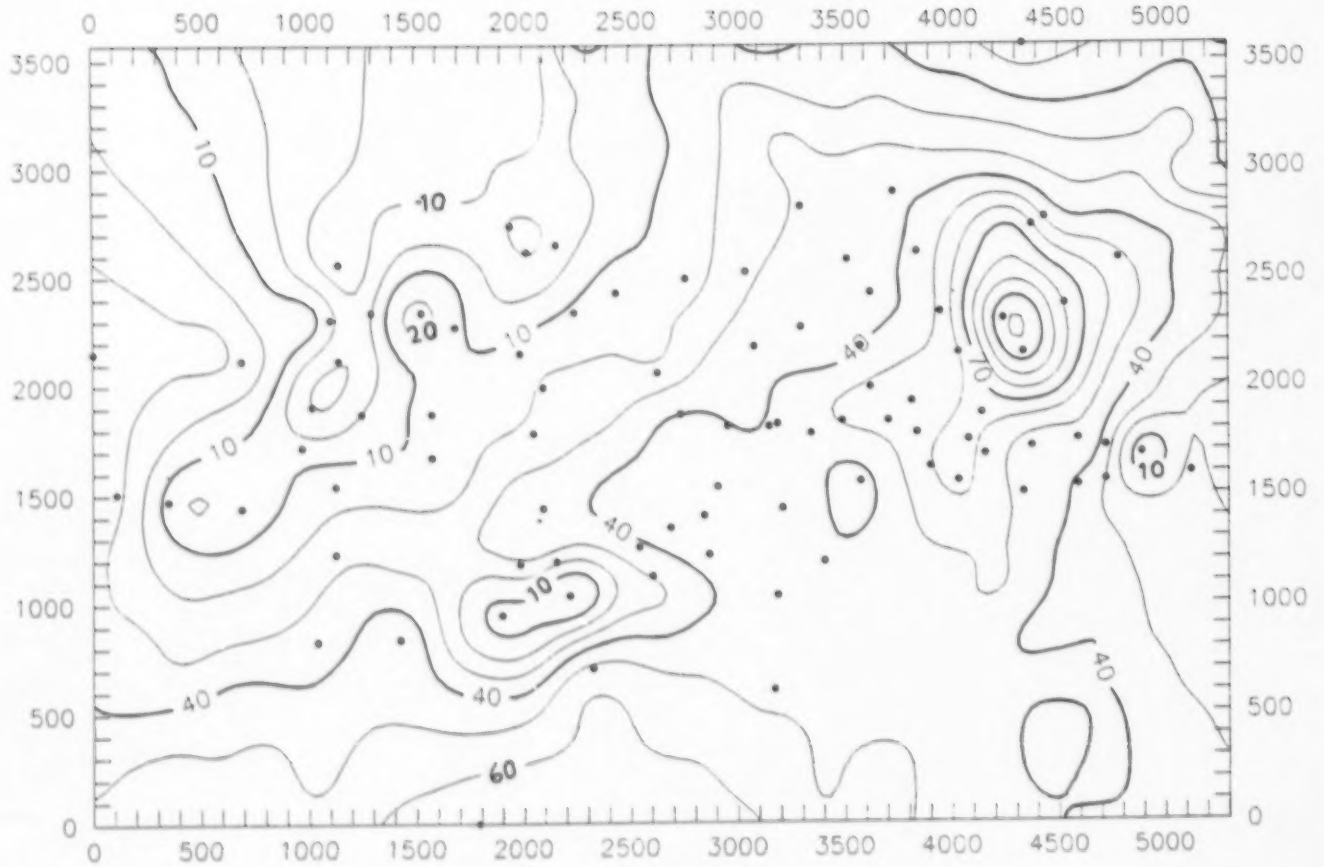


Figure 21: A computer generated structural contour map of the Enrage Unconformity. Contours represent the depth in metres relative to mean sea level. Coordinate axes are in metres.

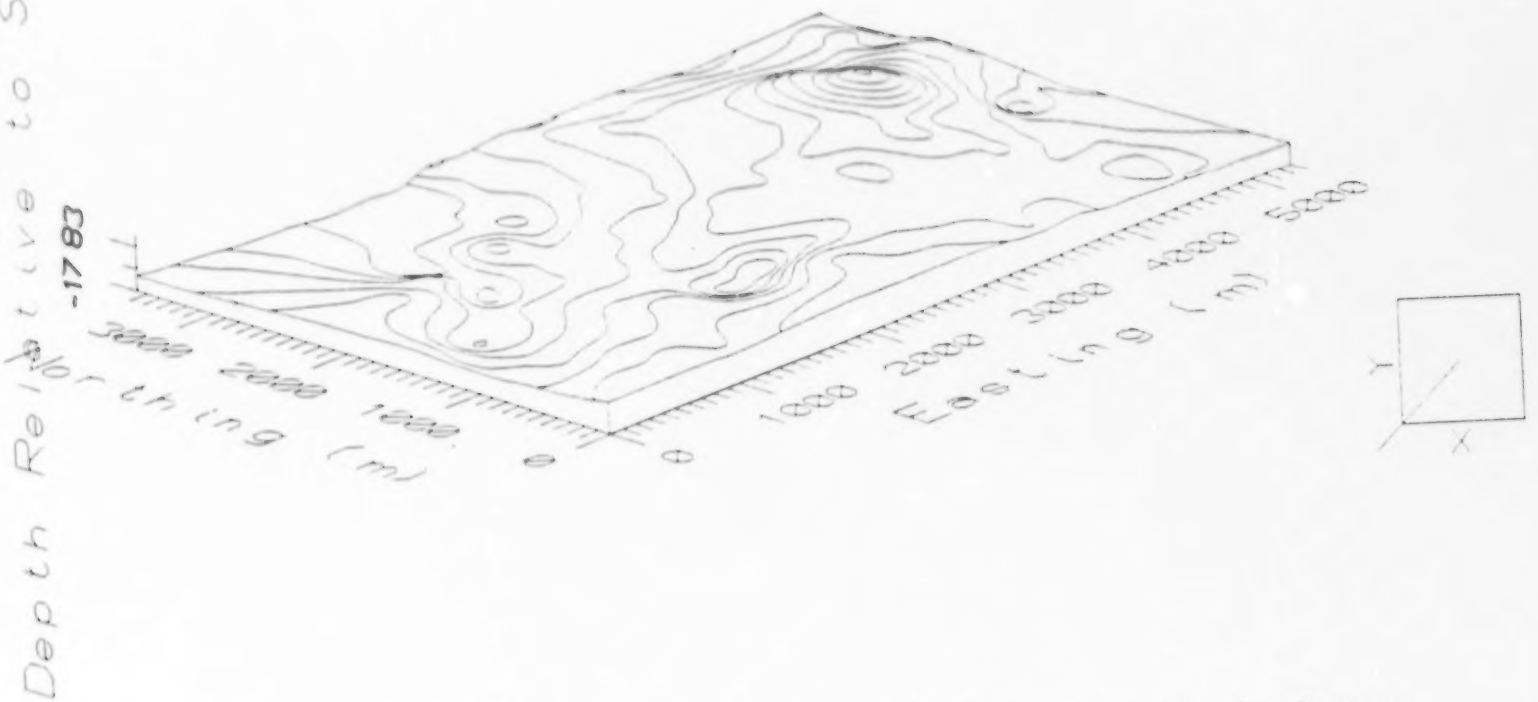


Figure 22: A computer generated stacked contour surface of the Enrage Unconformity (orthographic projection, tilt angle of 20 degrees). Vertical scale is in metres relative to sea level. See figure 21 for contour values.

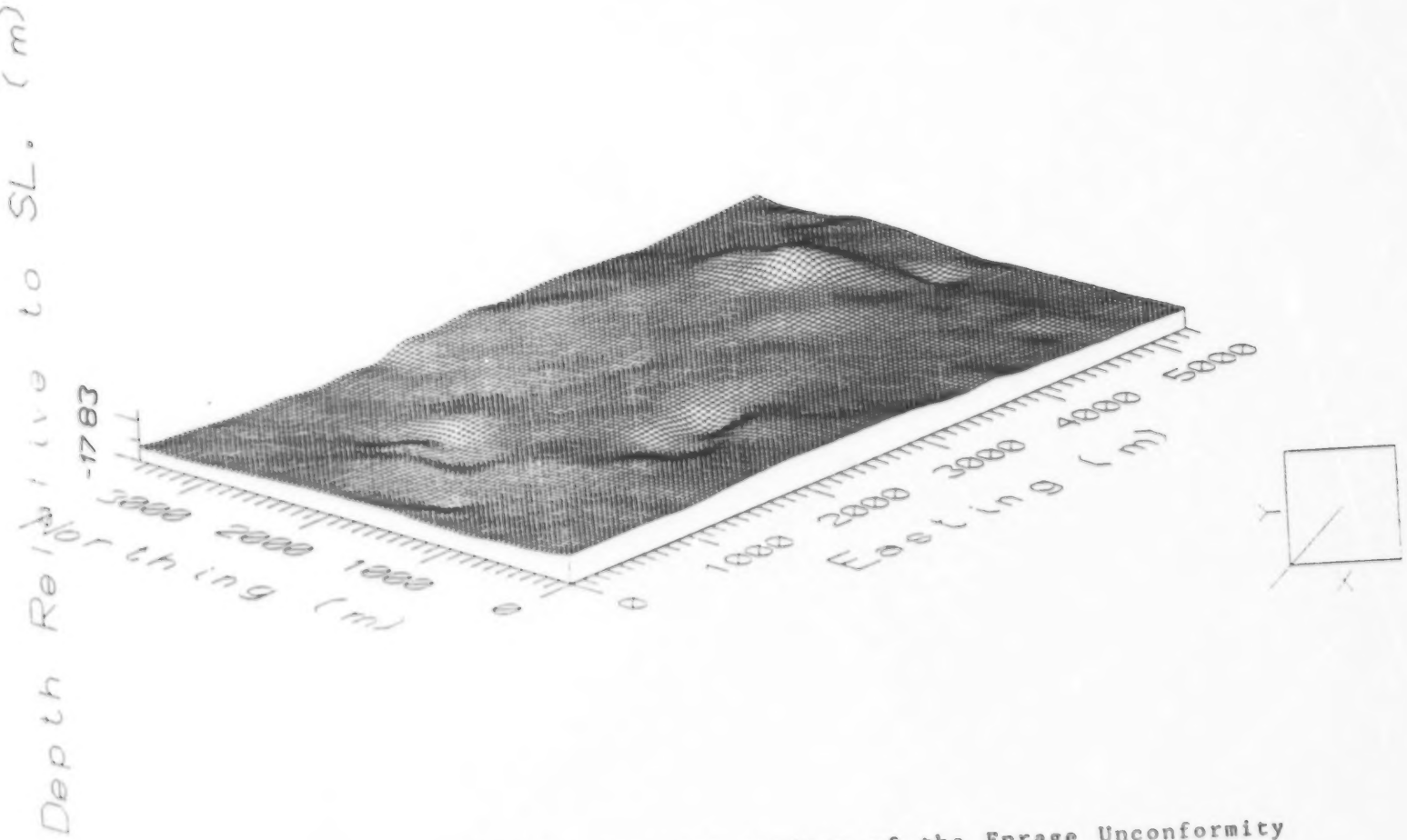


Figure 23: A computer generated transect surface of the Enrage Unconformity (orthographic projection, tilt angle of 20 degrees). Vertical scale is in metres relative to sea level.

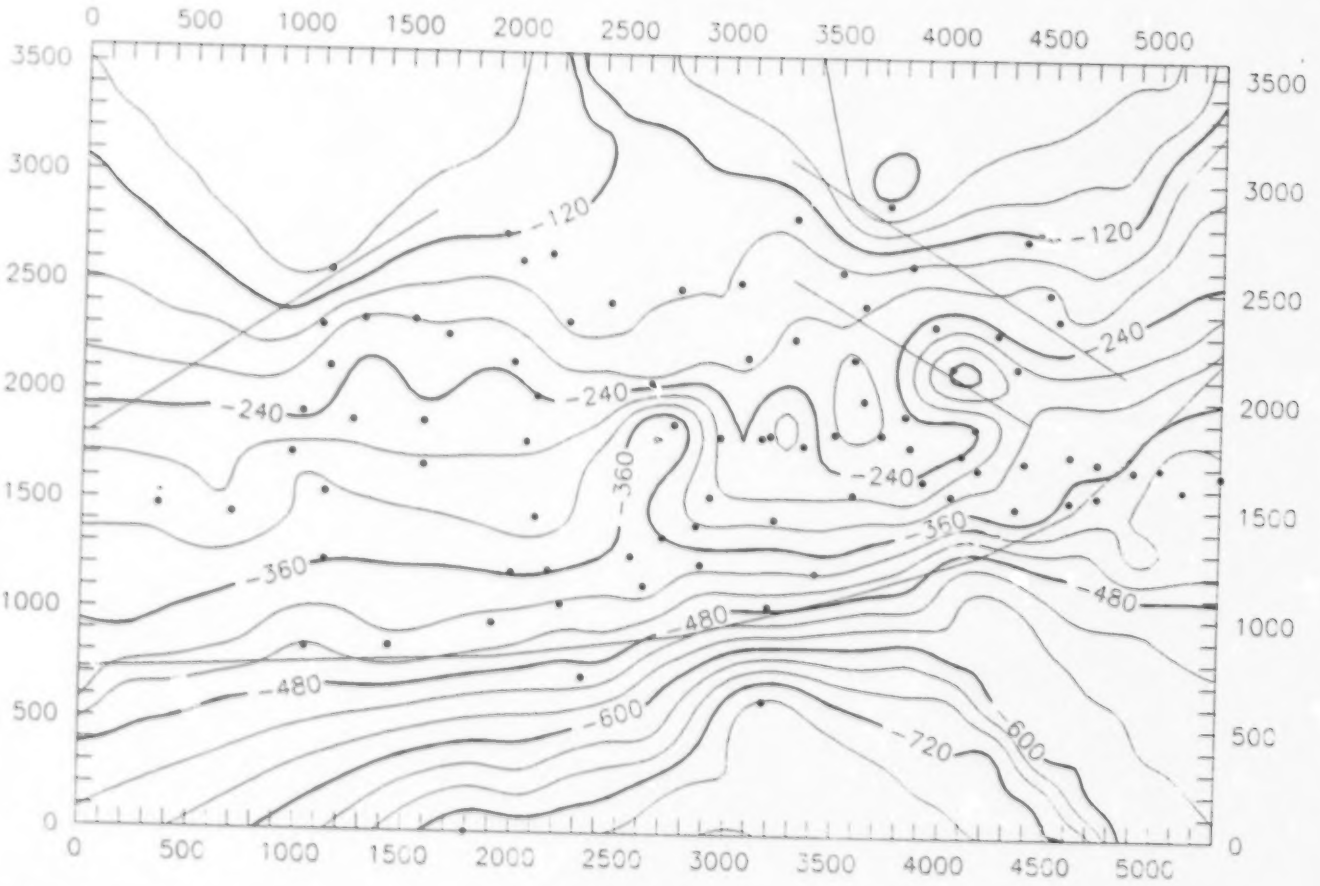


Figure 24: A computer generated structural contour map of the upper surface of sandstone zone 1. Contours record the depth in metres below mean sea level. Coordinate axes are in metres. Unbroken "straight" lines are faults.

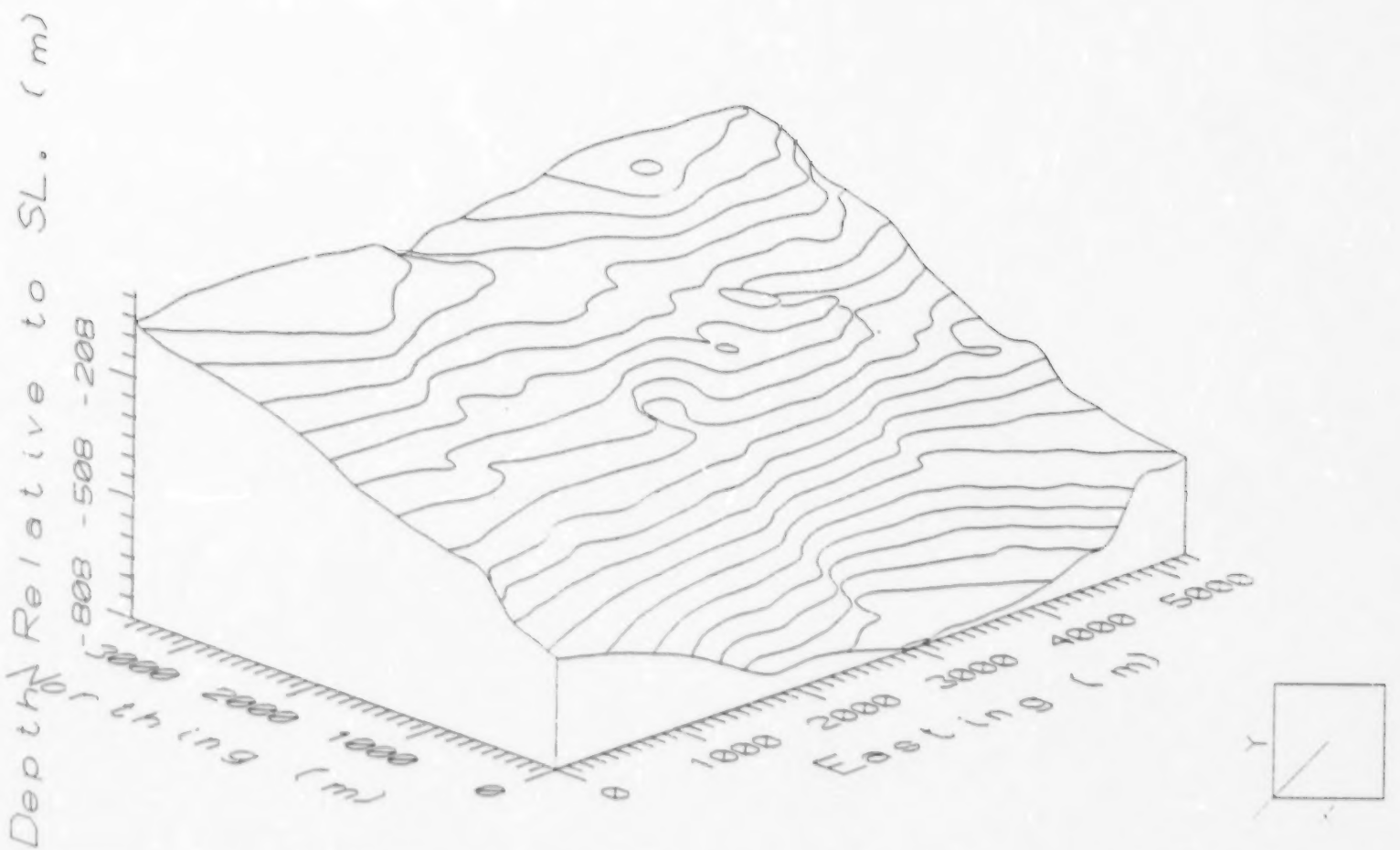


Figure 25: A computer generated stacked contour surface of the upper surface of sandstone zone 1 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. See Figure 24 for contour values.

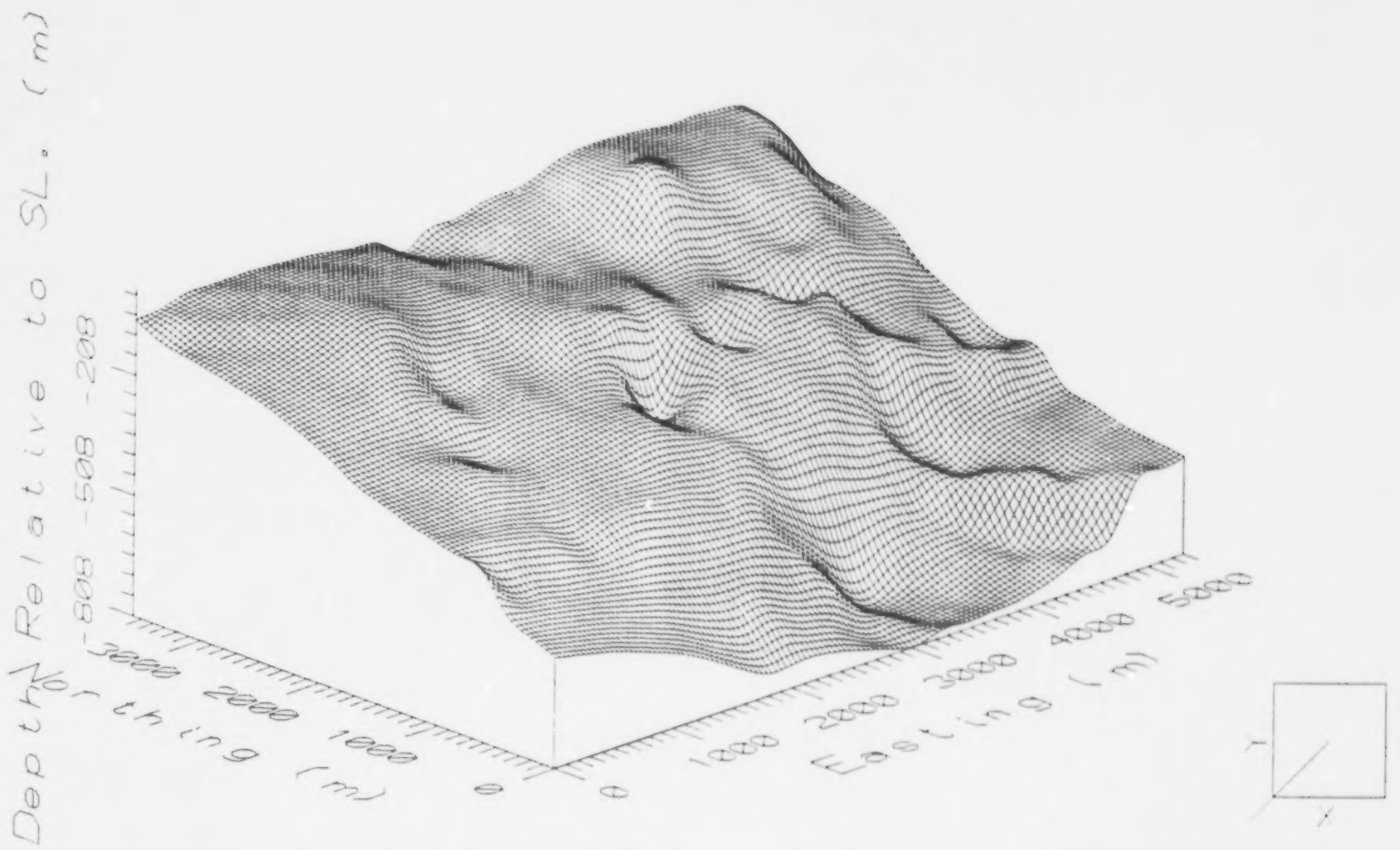


Figure 26: A computer generated transect surface of the upper surface of sandstone zone 1 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level.

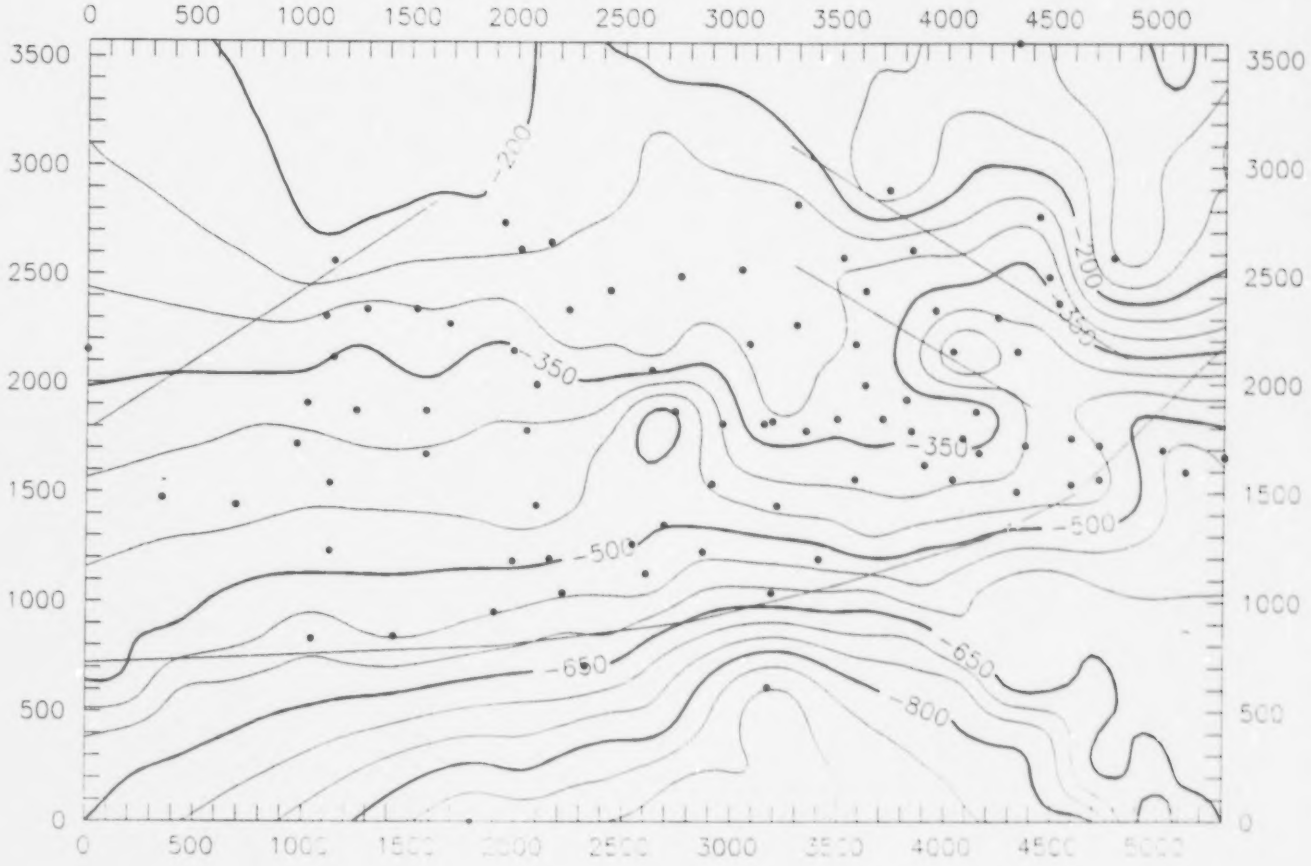


Figure 27: A computer generated structural contour map of the upper surface of sandstone zone 2. Contours record the depth in metres below mean sea level. Coordinate axes are in metres. Unbroken "straight" lines are faults.

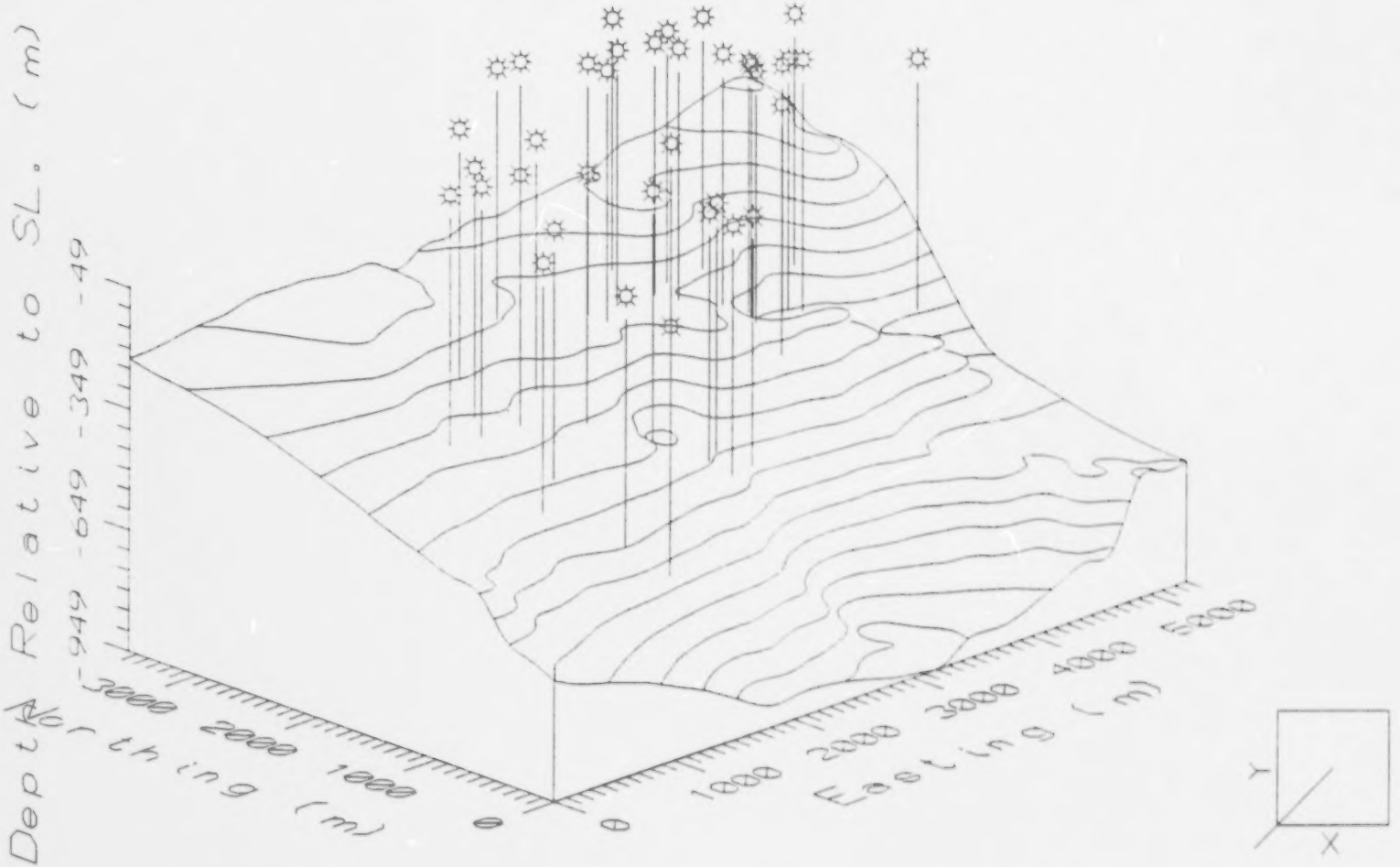


Figure 28: A computer generated stacked contour surface of the upper surface of sandstone zone 2 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. See Figure 27 for contour values. The wells are gas producers from zone 2.

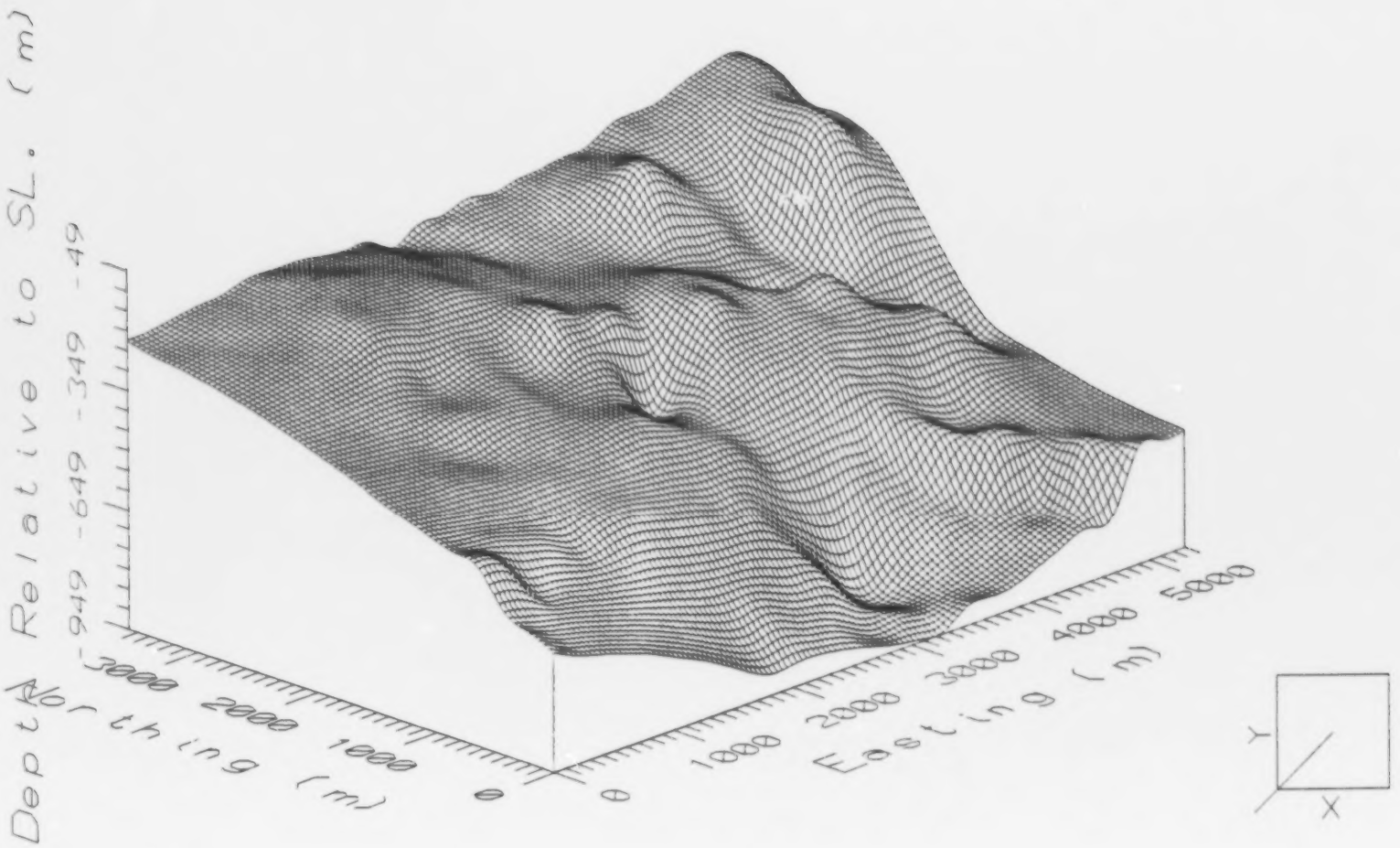


Figure 29: A computer generated transect surface of the upper surface of sandstone zone 2 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level.

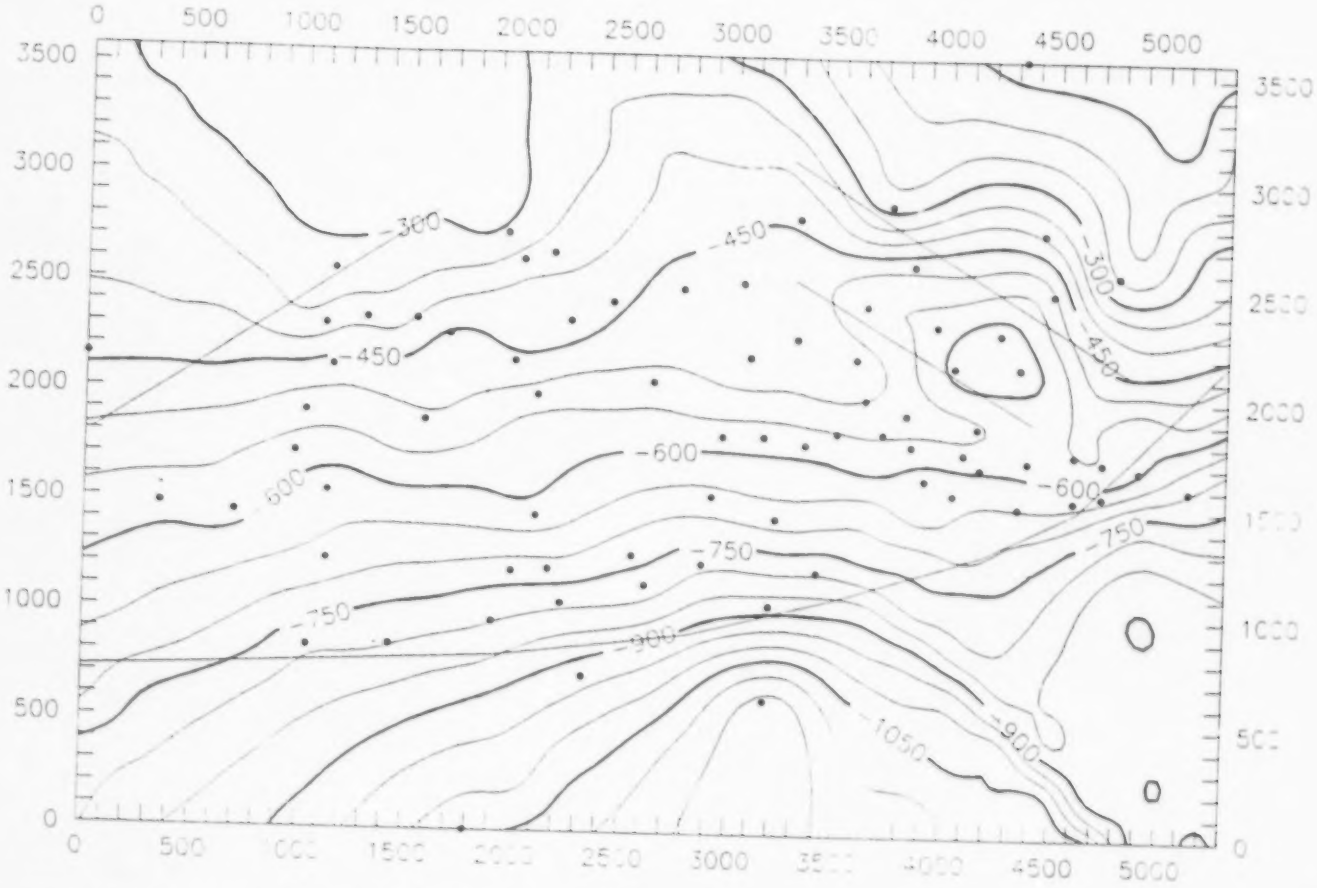


Figure 30: A computer generated structural contour map of the upper surface of the Frederick Brook Member. Contours record the depth in metres below mean sea level. Coordinate axes are in metres. Unbroken "straight" lines are faults.

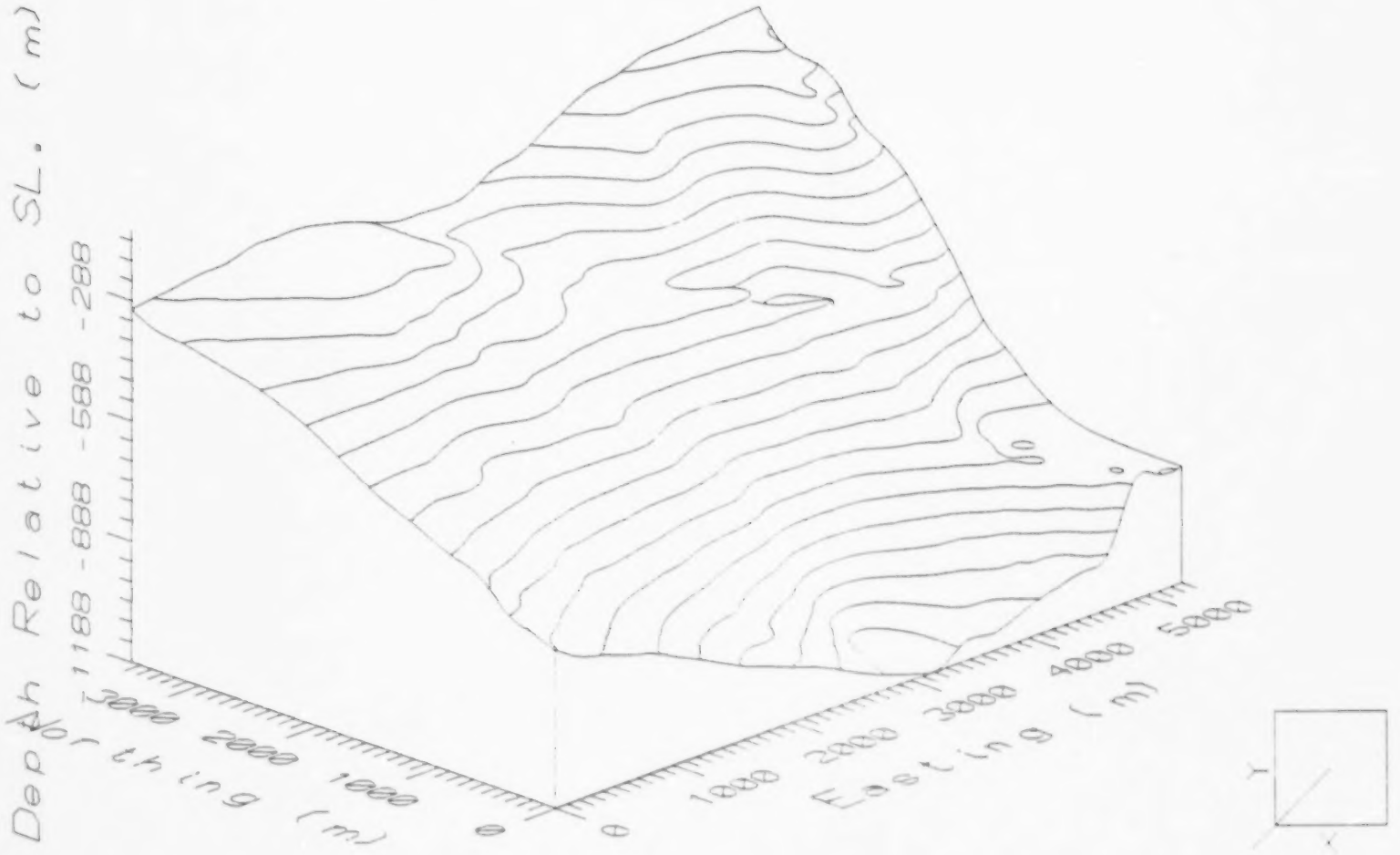


Figure 31: A computer generated stacked contour surface of the upper surface of the Frederick Brook Member (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. See Figure 30 for contour values.

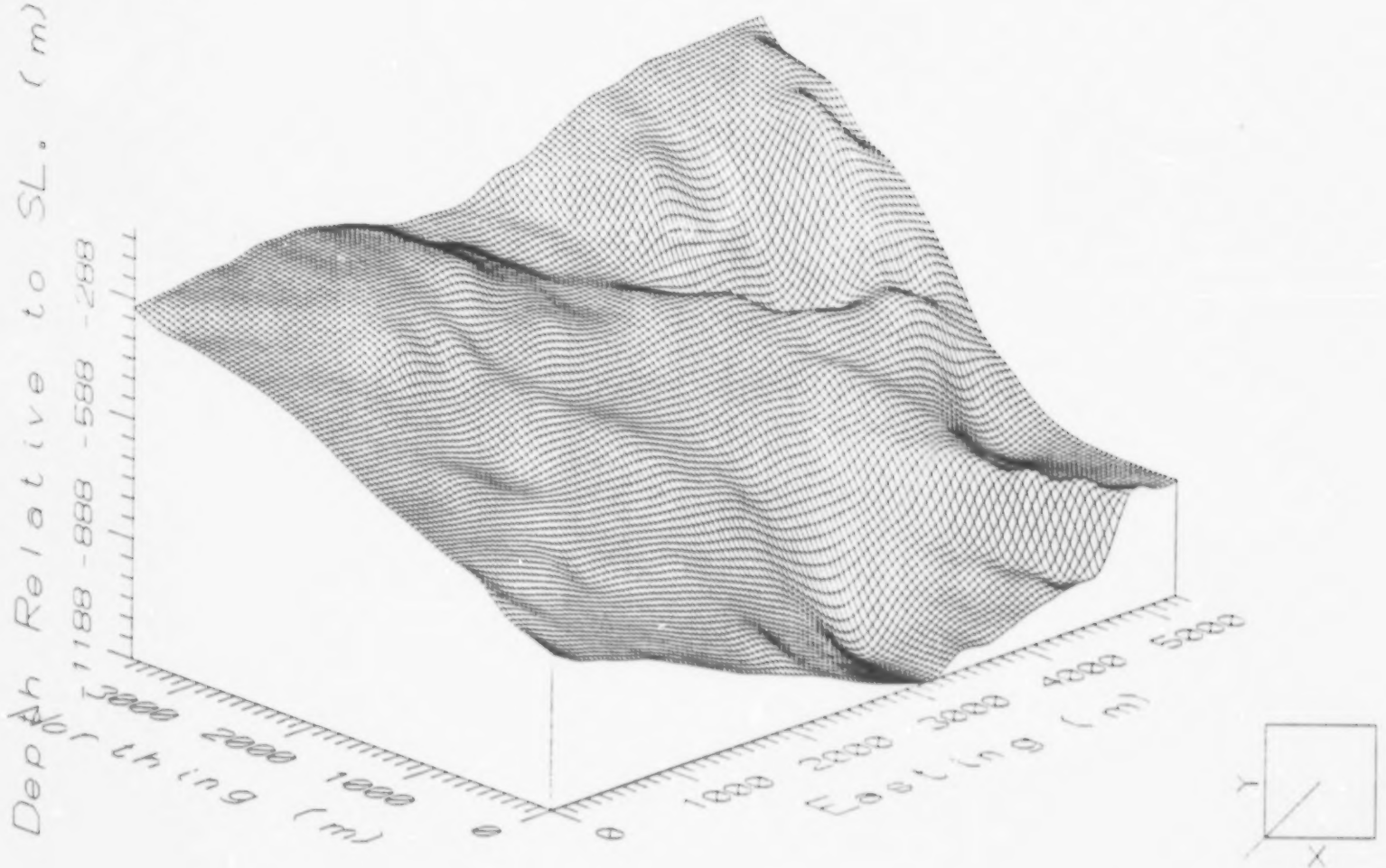


Figure 32: A computer generated transect surface of the upper surface of the Frederick Brook Member (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level.

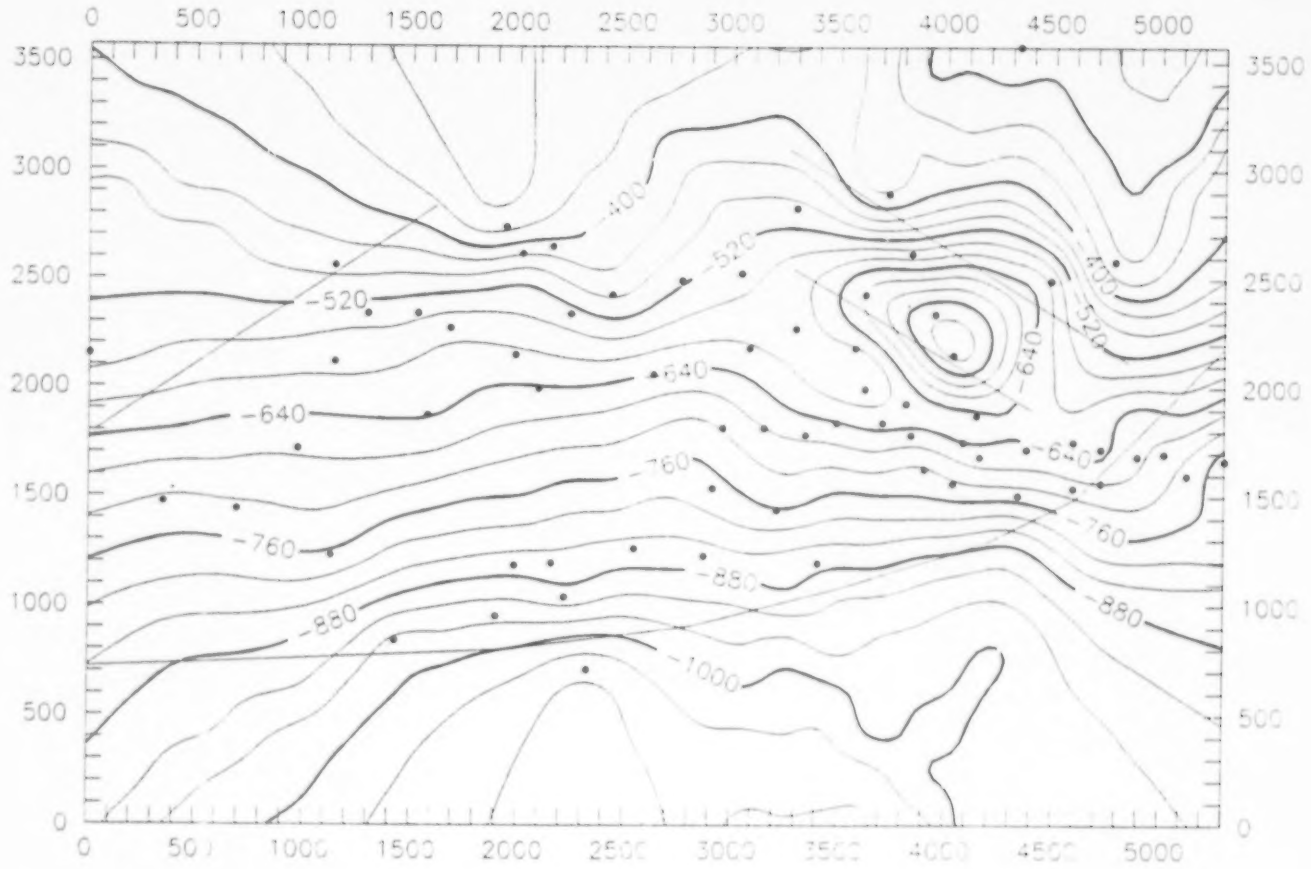


Figure 33: A computer generated structural contour map of the upper surface of sandstone zone 3. Contours record the depth in metres below mean sea level. Coordinate axes are in metres. Unbroken "straight" lines are faults.

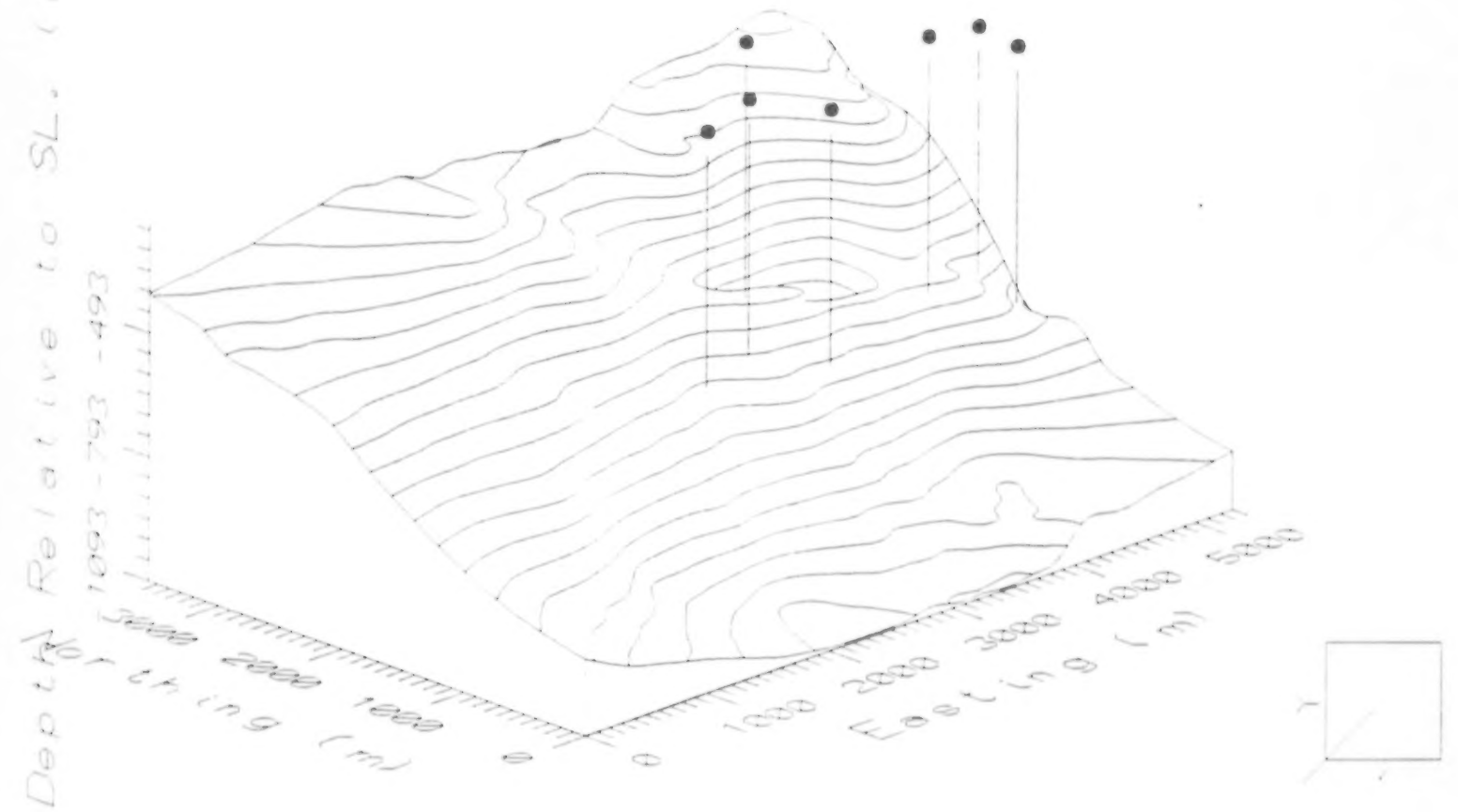


Figure 34: A computer generated stacked contour surface of the upper surface of sandstone zone 3 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level. See Figure 33 for contour values. The wells are oil producers from zone 3.

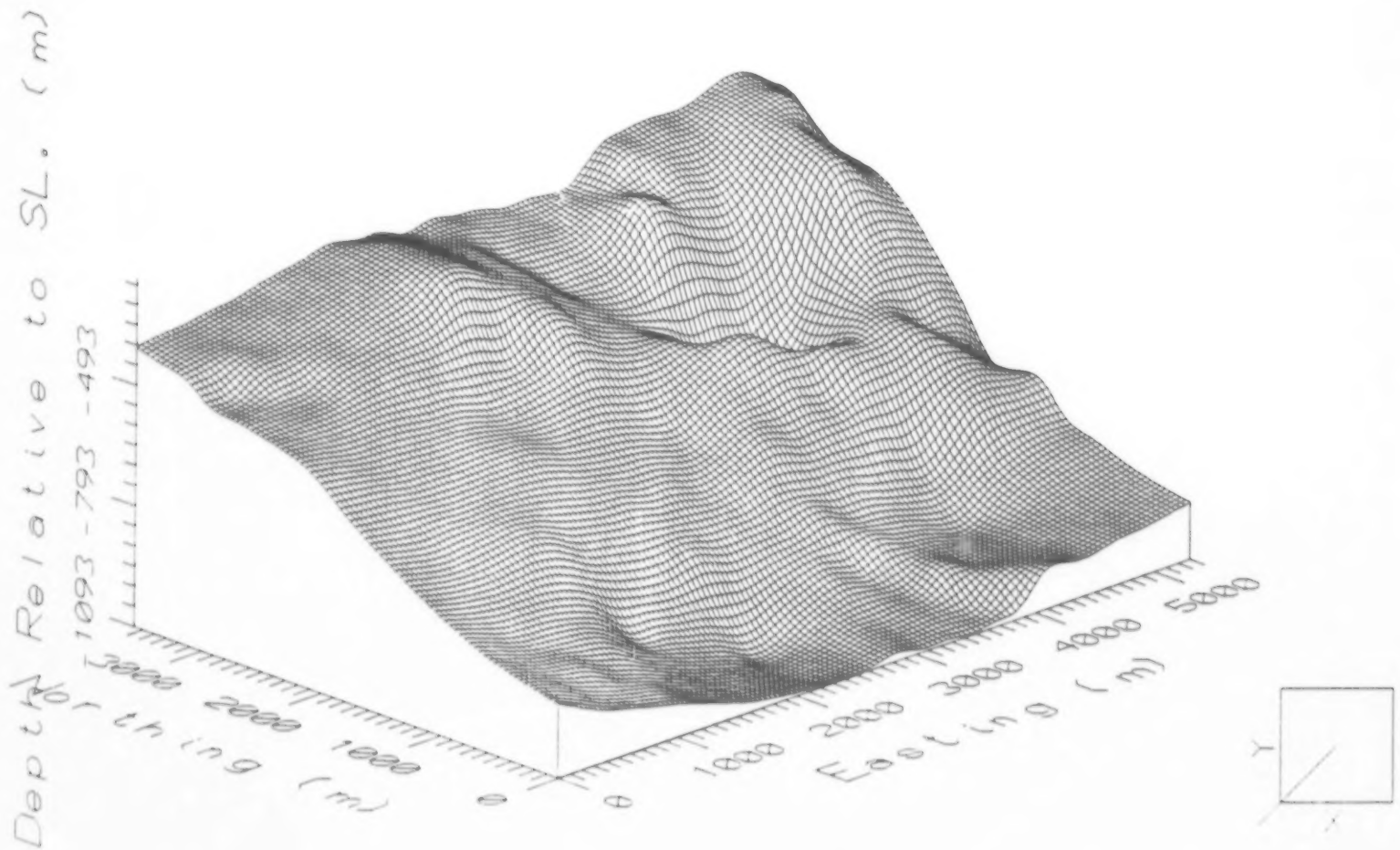


Figure 35: A computer generated transect surface of the upper surface of sandstone zone 3 (orthographic projection, tilt angle of 20 degrees). Vertical scale in metres below mean sea level.